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# COLONIC TRANSIT IN SUBJECTS WITH SPINAL CORD INJURIES

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NAT DIP RAD (D) (NM), DTR (UCT)

A THESIS PRESENTED FOR THE DEGREE OF

MSC (Med)

UNIVERSITY OF CAPE TOWN

# ACKNOWLEDGEMENTS

I wish to express my sincere thanks and appreciation to the following people:

All the subjects who so willingly gave up so much of their time to be part of this study and thereby make it possible.

To the staff of the Department of Nuclear Medicine and the Colo-rectal Unit in the Department of Surgery at Groote Schuur Hospital, for their co-operation and assistance.

Professor MD Mann, Head of the Department of Nuclear Medicine and the Poison Unit at Red Cross Hospital, for all his guidance and encouragement.

Professor P Goldberg, Head of the Colo-rectal Unit at Groote Schuur Hospital, for introducing me to the area of study and for his ongoing interest, endless patience, and willingness to share his expertise.

Dr S Isaacs of the Department of Medical Informatics at Groote Schuur Hospital, for all his assistance with the statistical analysis and his invaluable advice.

Dr AB Fataar, Senior Consultant in the Department of Nuclear Medicine at Groote Schuur Hospital, for all his support and forbearance.

Mr J Boniaszczuk, Chief Radiographer in the Department of Nuclear Medicine at Groote Schuur Hospital, for all his technical assistance, and his innovative problem-solving abilities.

Miss G Boltman, Chief Radiographer in the Department of Nuclear Medicine at Groote Schuur Hospital, for assisting me with the mysteries of the computer and problem-solving abilities and for the hours she spent helping me with the layout and printing of this thesis.

*My husband, Pip, for his unwavering support and for taking over all family responsibilities thereby making it possible for me to complete this thesis.*

*My children, Samantha and Jonathan, for their encouragement and sacrifices.*

# DECLARATION

I, **Patricia Noel Freedman**, declare that the work on which this thesis is based is my original work (except where acknowledgements indicate otherwise), and that neither the whole work nor any part has been, is being, or is to be submitted for another degree in this or any other university.

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# ABSTRACT

The rehabilitation of patients with spinal cord injuries (SCI) is long and difficult. Not only do they lose mobility but they also have changes in bowel continence caused by loss of voluntary motor and sensory function and damage to the visceral nerve supply. The maintenance and management of bowel function causes major morbidity for subjects with SCI. The effect of SCI on colonic function is poorly understood and little studied.

## Aim:

This study sought to establish a method of studying regional colonic transit and to investigate whether the level of SCI influences colonic transit.

## Patients and Methods

Sixteen subjects (8 paraplegics and 8 tetraplegics) with spinal cord injury, at least one year previously were recruited. The tetraplegics group had spinal cord injuries above T1 and the paraplegic group had injuries below T1. They were given a pancake labelled with 10-18 Mbq of In-111 Amberlite resin to eat. Anterior and posterior images were acquired for 400 seconds each, using a 40 cm field of view gamma camera, once on the first day and then 3 times a day for the next 4 days. The subjects were asked to report every time they had a bowel evacuation. No laxatives or enemas were permitted during the study. Subjects were permitted to eat and drink normally after the first images (3 hours) were acquired.

Seven regions of interest (ROI) outlining, 1) ascending colon, 2) hepatic flexure, 3) transverse colon, 4) splenic flexure, 5) descending colon, 6) rectosigmoid and 7) total abdominal activity, were drawn on each set of anterior and posterior images. The counts were decay corrected. The decay corrected counts were used to calculate the geometric mean (GM), for each region, at each time point. The GM was used to calculate the percentage of the total abdominal activity in each region, at each time point.

Colonic transit was assessed in 4 ways. Firstly, 3 independent Nuclear Medicine Physicians visually assessed transit on hard copies of the images and classified subjects into 5 categories of colonic transit (rapid transit, intermediate transit, generalised delay, right-sided delay or left-sided delay). Secondly, parametric images were constructed from the percentage activity in each region at each time point. Thirdly, the arrival and clearance times of the activity in the right and left colon were plotted as time-activity curves. Finally, the geometric centre of the distribution of the activity was calculated and plotted on a graph versus time. The parametric images, time activity curves of the right and left sides of the colon and the geometric centre for each subject were classified into the same categories as the visual assessment.

All statistics were assumed to be non-parametric.

## Results:

The results of the four methods of assessing colonic transit were compared and the majority categorisation was accepted as the final diagnosis. The best agreement occurred between the parametric images and the arrival and clearance times of the activity in the right and left colons. No single method was consistently correct.

Amongst the paraplegic subjects, two had generalised delay, four had right-sided delay, and two left-sided delay. In the tetraplegic subjects, two had intermediate transit, 1 generalised delay, and 5 left-sided delay.

## Conclusion

A combination of at least two methods of determining colonic is necessary. The level of spinal cord injury effects colonic transit. Injuries below T7/T8 result in right-sided delay. Injuries above this most commonly result in left-sided delay. Occasionally injuries above T7/8 can result in intermediate transit or generalised delay.

Paraplegics are more likely to have right-sided delay ($p=0.04$), whereas tetraplegics are more likely to have left-sided delay.

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# ABBREVIATIONS

AC: Ascending colon

C: Cervical Spine

Cnts: Counts

Com: Complete

DC: Descending colon

DCC: Decay corrected counts – counts corrected to time zero

% Diff: Percentage difference between total counts from two consecutive times of imaging

EAS: External anal sphincter

EDE: Estimated dose equivalent

g Gram

GC: Geometric centre

Gen Delay: Generalised delay

GM: Geometric Mean

HCl Hydrochloric acid

HF: Hepatic flexure

IC: Incomplete

Intermed: Intermediate transit

keV: Kiloelectron volt

L: Lumbar spine

LMN: Lower motor neuron

Manip: Manipulation

MBq: Megabecquerel

ml Millilitre

| | |
|---|---|
| mSv: | millisievert |
| MVA: | Motor vehicle accident |
| R/S: | Recto-sigmoid |
| ROI(S): | Region(s) of interest |
| S: | Sacrum |
| SCI: | Spinal cord injury |
| SF: | Splenic flexure |
| SQRT: | Square root |
| T: | Thoracic spine |
| t½: | Half-life of radionuclide |
| TC: | Transverse colon |
| TCC: | Time corrected counts – counts corrected to 400sec acquisition time |
| Tot: | Total |
| UMN: | Upper motor neuron |

# INTRODUCTION

The life span of spinal cord injured subjects is increasing because of improved treatment and post injury care. Problems caused by spinal cord injuries are therefore becoming more significant. Spinal cord injured subjects rate bowel and bladder dysfunction as having major effects on their lives.

Chronic constipation and faecal incontinence are the two main gastrointestinal problems following spinal cord injury. These two problems can have a big impact on the injured subjects lives. They often need caregivers to assist with bowel management, their social interaction is reduced and gainful employment is difficult. Various methods of managing bowel constipation and continence are used. A colostomy can simplify bowel management but in order for it to be effective it must be correctly sited.

Regional colonic transit in paraplegic and tetraplegic subjects was studied in order to establish whether the level of spinal cord injury had a recognisable effect on the pattern of colonic transit.

A radiolabelled meal was chosen to study regional colonic transit as it is non-invasive and reproducible.

# LITERATURE REVIEW

## SPINAL CORD INJURY

### Incidence

Traumatic spinal cord injury affects all aspects of the injured persons life. The main cause of spinal cord injury differs from country to country (Table 1). Currently in South Africa, assault accounts for 56% (gunshots 36%, stab wounds 20%) motor vehicle accidents 25%[1], and falls from heights 2.4%. The injury primarily affects young males[1, 2].

**TABLE 1**

| | MVA | GUNSHOT | STABS | FALLS |
|---|---|---|---|---|
| South Africa[1] | 25.0 | 36.0 | 20.0 | 2.4 |
| Spain[3] | 52.2 | 3.2 | - | 27.4 |
| Turkey[4] | 35.4 | 21.9 | - | 29.5 |
| France[5] | 50.7 | 2.0 | - | 31.5 |
| Australia[4] | 48.7 | 5.8 | - | 26.6 |
| USA[5-7] | 42.8 | 12.3 | - | 19.2 |
| England[4] | 46.8 | 0 | - | 25.7 |
| Nigeria[8] | 75.0 | - | - | 23.0 |

*Aetiology of spinal cord injury in different countries (percentages)*

## Definition of paraplegia and tetraplegia

Nerve conduction is disrupted at the site of injury of the spinal cord. The level of the spinal cord injury will determine whether the person is classified as a paraplegic or a tetraplegic.

- Paraplegia is defined as a loss or impairment of motor or sensory function, or both, in the thoracic, lumbar or sacral segments of the spinal cord. The level of injury determines whether the trunk, legs and pelvic organs are involved. The function of the arms is spared.
- Tetraplegia involves loss or impairment of motor or sensory function, or both, in the cervical segments of the spinal cord. This causes impairment in the function of the arms, trunk, legs and pelvic organs[9].

## Assessment of functional impairment

Various methods are used in the assessment of the functional impairment of spinal cord injured subjects. The Frankel scale (Table 2) is widely used clinically in South Africa. It is simple to use and has the advantage of allowing the comparison of large numbers of patients because it eliminates the variations caused by different examiners in grading motor power and sensory perception[10, 11]. The Scale is ideal for comparing groups of patients during a research project, and comparing different research results with one another[10].

An alternative is the American Spinal Injury Association impairment scale. It is based on the Frankel scale but, in addition, specifically defines the involvement of S4-S5. This scale is not used at our institution. The staging used in both scales is identical[9].

**TABLE 2**

**Frankel scale**[11]

| | |
|---|---|
| A | **Complete:** No sensory or motor function is preserved. |
| B | **Incomplete (Sensory Only):** Sensory but not motor function is preserved below the neurological level. |
| C | **Incomplete (Motor Useless):** Motor function is preserved below the neurological level. The majority of key muscles below the neurological level have a muscle grade less than 3. |
| D | **Incomplete (Motor Useful):** Motor function is preserved below the neurological level. The majority of key muscles below the neurological level have a muscle grade greater than or equal to 3 |
| E | **Normal (Recovery):** Sensory and motor function is normal. (Reflexes may be abnormal) |

## THE COLON

The colon commences in the right iliac fossa at the caecum. It extends, as a retroperitoneal structure, through the right lumbar region and hypochondrium to the under surface of the liver. It then bends to the left (hepatic flexure) and extends across the abdomen to the left hypochondrium, as an anterior structure. It extends downwards (splenic flexure) through the left lumber region to the left iliac fossa as a retroperitoneal structure. It then forms the sigmoid colon, which is again an anterior structure. It finally enters the pelvis and extends along the anterior surface of the sacrum to the anus, as a posterior structure. The transverse and sigmoid colons are suspended on mesenteries. They are therefore mobile structures.

The muscular coat of the colon consists of two layers, an external longitudinal layer of smooth muscle that is condensed into three longitudinal bands and an inner layer which is circular. The rectum differs from the colon in that the external layer of longitudinal fibres is a continuous investing layer[12].

The colon has 2 main roles:

- Absorption of water and electrolytes from chyme.
- Storage of faeces until defaecation.

It achieves these functions by 2 different motility patterns:

- Mixing movements: Segmentation with localised mixing of the colonic contents exposes the faecal material to the surface of the large intestine. This allows fluid to be progressively absorbed reducing the water content by about 90%. There is also slow movement of the contents towards the anus during the mixing movements. This is the main form of movement in the proximal colon. It takes between 8 and 15 hours for colonic content to pass from the ileocaecal valve to the distal transverse colon.
- Propulsive movements: The major form of propulsion in the left colon is in the form of 'mass movements'. They only occur a few times a day, and are most common shortly after breakfast. These mass movements are characterised by the rapid movement of a contraction ring towards the anus, propelling all faeces *en masse* ahead of it. When the faeces reach the lower rectum, the desire to defaecate is felt.[13].

Normal colonic transit takes between 24 and 48 hours from ileocaecal valve to anus[14-16].

## EMBRYOLOGY OF THE COLON

The proximal colon from the caecum to approximately the splenic flexure is derived embryologically from the midgut. It is supplied by the artery of midgut (superior mesenteric) and has the nerve supply of the midgut. The colon distal to the splenic flexure derives from the hindgut. It is supplied by the artery of the hindgut (inferior mesenteric), and its nerve supply[17].

## INTRINSIC NERVOUS SYSTEM

The gastrointestinal tract has an intrinsic nervous system. This system is influenced by both the parasympathetic and the sympathetic nervous systems and controls most of the gastrointestinal functions, especially movement and secretion. The intrinsic nervous system of the gut is the only division of the peripheral nervous system that is able to mediate reflex activity without input from the central nervous system[18].

### Myenteric Plexus and Submucosal Plexus

The intrinsic nervous system is composed of two layers of neurons and appropriate connecting fibres. The outer layer is the myenteric plexus or Auerbach's plexus, which lies between the longitudinal and circular muscle coats. The inner layer is the submucosal plexus or Meissner's plexus and this lies in the submucosa[19].

Stimulation of the myenteric plexus increases motor activity of the gut resulting in four main effects:

1. Increased tone of gut wall
2. Increased intensity of rhythmic contractions
3. Increased rate of rhythmic contractions
4. Increased speed of conduction of excitatory waves along gut wall.

Some myenteric fibres are inhibitory.

The submucosal plexus controls secretion and blood flow and has sensory functions. It receives signals mainly from gut epithelium and stretch receptors in the gut wall[18].

## AUTONOMIC CONTROL OF THE COLON

The extrinsic innervation takes place via the autonomic nervous system. This is subdivided into parasympathetic and sympathetic. These alter the overall activity of the entire gut.

### Sympathetic innervation

The sympathetic pathway consists of two fibres, a preganglionic neuron and a postganglionic neuron.

The preganglionic neuron extends through an anterior root cord into a spinal nerve. Once outside of the spinal cord it extends from the spinal nerve to one of the sympathetic ganglia. The fibres ultimately end in one of the outlying sympathetic ganglia. Postganglionic neurons arise in either the sympathetic ganglia or in one of the outlying ganglia. From there they spread to various organs[18].

The sympathetic outflow to the proximal colon arises in the lateral columns of T4 – T12 of the spinal cord. The fibres pass through the coeliac and superior mesenteric ganglia to reach the midgut[19].

The outflow to the hindgut arises in the lateral columns of the upper three lumbar vertebrae. It passes through the lumbar splanchnic nerves to join the preaortic plexus and from there to the inferior mesenteric plexus where the nerves synapse. Postganglionic fibres travel with the inferior mesenteric artery to supply the left colon and upper rectum[19]. Those fibres destined to supply the lower rectum and anus synapse in the hypogastric plexus and form the presacral nerves[18].

Sympathetic stimulation causes a decrease in colonic contractility and motility, and increases internal anal sphincter pressures[19].

## Parasympathetic innervation

The parasympathetic supply to the gut is divided into two parts, the cranial and the sacral. The cranial division arises from the 10$^{th}$ cranial nerve nuclei in the medulla oblongata and supplies the fore and midgut via the vagus nerves.

The sacral parasympathetic fibres arise from sacral parasympathetic centres in the spinal cord. They leave the spinal cord through S2 to S5 and pass as nervi erigentes to join the pelvic plexus. From here they spread, via the pelvic nerves, to the hypogastric plexus and inferior mesenteric plexus to supply the territory of the inferior mesenteric artery[20].

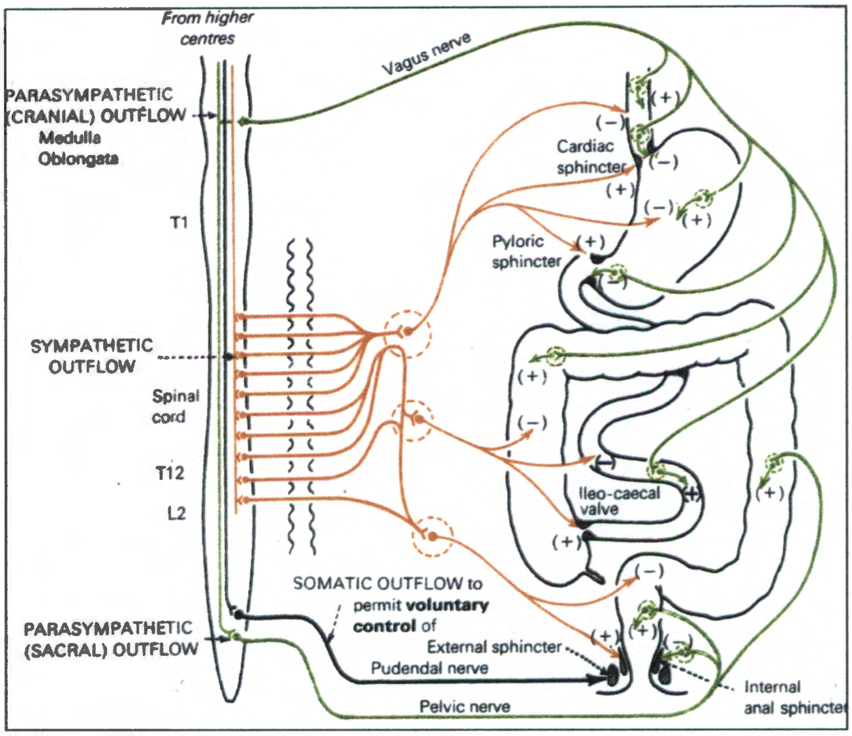
Parasympathetic preganglionic fibres terminate in the organ to be controlled, where they synapse with postganglionic neurons. The postganglionic neurons are mainly located in the myenteric and submucosal plexuses[13]. Stimulation of the parasympathetic nerves causes a general increase in activity of the intrinsic nervous system. In the colon, this results in an increase in colonic contractility, motility and tone. The internal anal sphincter relaxes[19].

## Gastrointestinal reflexes

The anatomical arrangement of the intrinsic nervous system and its connection to the parasympathetic and sympathetic nervous systems supports three different types of gastrointestinal reflexes.

- Reflexes that are entirely within the intrinsic nervous system such as reflexes that control gastrointestinal secretion and peristalsis.
- Reflexes from the gut to prevertebral sympathetic ganglia and back to the gut such as the gastrocolic, enterocolic and colonoileal reflexes.
- Reflexes from gut to spinal cord or brain stem and back to gut. Examples include reflexes that control gastric motor or secretory activity, pain reflexes, and defaecation reflexes[13].

## DIAGRAM 1




*The autonomic nervous system controlling colonic innervation. (From McNaught A, Callander R, Illustrated Physiology. Fifth Edition, Edinburgh, Churchill Livingstone 1975)*

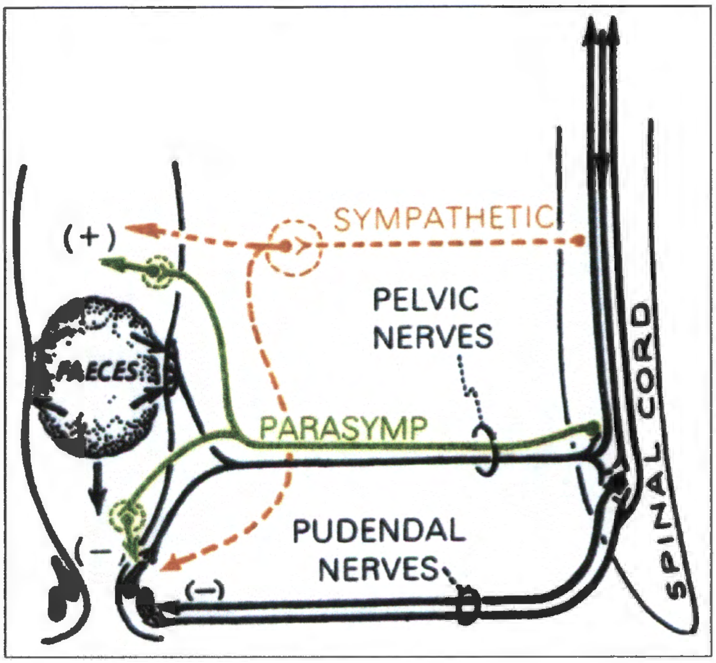
## CONTINENCE

The rectum, is a continuation of the colon and by convention, begins at the level of the sacral promontory, where the condensed longitudinal layer of muscle becomes continuous. It ends at the upper end of the anal sphincter. The anus consists of an inner thickened smooth circular muscle layer (internal anal sphincter), surrounded by voluntary striated muscle (external anal sphincter). The rectum forms a compliant reservoir that is usually empty of faeces. The internal anal sphincter generates approximately two thirds of the resting anal tone. The external sphincter generates the remaining one third of resting anal tone. It is unique amongst skeletal muscle because there is always some activity, even during sleep.

The faecal mass tends to remain above the rectosigmoid junction. A propulsive wave consisting of an area of relaxation followed by an area of contraction propels faecal contents into the rectum often as part of a 'mass movement'. This propulsive wave continues into the upper anal canal. The internal sphincter relaxes ahead of the bolus of faeces (recto-anal inhibitory reflex). When the bolus reaches the transitional zone (in the anal canal) just above the dentate line, sensory neurons sample it, a conscious decision is made to increase the external anal sphincter tone and the bolus is returned to the rectum where receptive relaxation occurs.

As the faecal contents accumulate in the rectum, the rectal wall stretches[19, 21]. This stretch starts afferent signals that cause the myenteric plexus to initiate peristaltic waves in the descending colon, sigmoid and rectum. Stimulation of afferent parasympathetic fibres in the rectal wall enhances peristalsis in the left colon via the spinal reflex arc. The peristaltic waves propel faecal contents into the anal canal. The internal sphincter relaxes ahead of the peristaltic wave. Should defaecation be appropriate, the external sphincter relaxes. The afferent signals to the spinal cord cause other effects to take place, such as taking a deep breath, the closure of the glottis, and contraction of the abdominal muscles.This raises the intra abdominal pressure and promotes defaecation[19, 21].

**DIAGRAM 2**




*The nerves controlling defaecation. (From McNaught A, Callander R, Illustrated Physiology. Fifth Edition, Edinburgh. Churchill Livingstone 1975)*

## SPINAL CORD INJURY AND THE GUT

Colorectal function is controlled by a combination of neural, hormonal, and luminal influences. Following spinal cord injury, many of the normal regulatory mechanisms, such as endocrine, as well as luminal influences, remain intact. However there is loss of central control of the gut and alteration of the function of the denervated hindgut.

## SPINAL SHOCK

Spinal shock occurs when the spinal cord is suddenly and completely transected. This results in a permanent loss of all voluntary and sensory function and a temporary loss of reflex function below the level of injury. This produces a disturbance in the intrinsic peristalsis of the intestines. The excitatory influences of the supraspinal centres are suddenly withdrawn from the spinal cord resulting in temporary depression of the segments distal to the injury. The sacral reflexes that control the bladder and colon evacuation are completely suppressed for a few weeks. Reflex ileus is the most common gastrointestinal complication during this period. The level and completeness of injury determines the duration, extent and time of onset of ileus[22, 23]. At the end of the spinal shock phase, reflex activity returns[19, 24].

## POST SPINAL SHOCK

Following the spinal shock phase, the spinal neurons gradually recover. Loss of input from higher centres results in an increase in their inherent excitability. This leads to hyperexcitability of cord functions. The sacral reflexes controlling evacuation return to normal after a few weeks if the injury lies above the conus medullaris. If the conus medullaris is destroyed then defaecation is completely paralysed[25].

Spinal cord injury results in the disruption of the autonomic nervous system. The parasympathetic activity is preserved because the vagus and pelvic nerves usually escape injury. The pelvic parasympathetic nerves are released from central control. Sympathetic input is disrupted because the preganglionic fibres are situated in the thoracolumbar interomediomedial and interomediolateral cell column of the spinal cord from T4- L3[26]. If the injury lies above T4-T6 separation from central sympathetic control is complete[26]. The parasympathetic activity remains unchecked, causing an autonomic nervous system imbalance[27]. This imbalance might explain many of the gastrointestinal complications[24, 26].

## DEFAECATION AFTER SPINAL CORD INJURY

In spinal cord injuries the cord-mediated defaecation reflex is either blocked or altered. If the spinal cord injury lies somewhere between the conus medullaris and the brain, then the voluntary part of defaecation is blocked but the anal reflexes for defaecation are still intact. The loss of the voluntary aid to defaecation, i.e. the loss of increased abdominal pressure makes evacuation difficult. Subjects become constipated because of incomplete evacuation. Reflex rectal evacuation can be stimulated by enemas[28].

Upper motor neurone bowel occurs if the spinal cord lesion lies above the conus medullaris. Stiens, Bergman and Goetz[29] describe the colon as "spastic" because of increased colonic wall tone. The pelvic floor and external anal sphincter are spastic. This leads to faecal retention. These subjects need chemical treatment to trigger defaecation[29].

Cauda equina lesions produce a variable picture. Most subjects are incontinent. The entire sacral outflow is destroyed leading to a decrease in anal tone because the external sphincter is paralyzed. There is no awareness of faecal leakage because the perineum is anaesthetic and there is no voluntary control over defaecation. The rectum enlarges, compliance increases with little contractile activity in response to rectal distension. Rectal sensation is blunted and is felt as abdominal not perineal discomfort. The rectoanal inhibitory reflex remains intact but there is no reflex contraction of anal sphincters[28, 30].

Lower motor neurone bowel is caused by a lesion that affects the parasympathetic cell bodies at the conus medullaris, their axons in the cauda equina or the pelvic nerve. The colon tends to be relaxed and no reflex spinal cord mediated peristalsis takes place. Water absorption continues to take place as the stool is slowly propelled by segmental peristalsis co-ordinated by the myenteric plexus alone. Incontinence can occurs because the external anal sphincter is denervated.

If the conus medullaris of the spinal cord is destroyed then the sacral centres, where the cord reflex is integrated, are also destroyed. This almost completely paralyses defaecation.

## CONSTIPATION

Chronic constipation is one of the most common gastrointestinal symptoms following spinal cord injury. According to Menardo et al[31] *"complete transection of the spinal cord is inevitably followed by constipation that is generally unresponsive to usual conservative management"*. Chronic constipation in normal individuals can be defined as the presence of the following complaints, for at least a year, when not taking laxatives:

An average of less than two bowel movements a week or two or more of the following

a straining in at least 25% of bowel movements

b a sensation of incomplete evacuation at least 25% of the time

c hard or pellet-like stools in at least 25% of bowel movements

d less than three bowel movements a week[32].

After spinal cord injury, straining is not possible and the sensation of incomplete evacuation is usually absent.

## BOWEL MANAGEMENT

The effect of spinal cord injury on the bowel has a profound impact on the social activities and quality of life of spinal cord injury subjects. The ability of spinal cord injury subjects to cope with neurogenic bowel dysfunction independently is limited, irrespective of their degree of physical disability. This means a caregiver has to assist with bowel management. If the caregiver is a family member, it can lead to strained relationships within the family. The need for a caregiver results in loss of dignity and privacy for the subject. Bowel function limits social interactions and makes leaving the home difficult. This impacts on travel and working away from home and has major economic implications[29, 32, 33].

With improved treatment and care, spinal cord injury subjects are living for much longer and gastrointestinal complaints are becoming a significant problem[34]. In a survey carried out by Wilson et al[35] bowel management proved to be a primary problem for patients with spinal cord injuries as well as for their families and care-givers. Under poor socioeconomic conditions bowel problems become more difficult to tolerate.

In a survey conducted by Stiens et al[29] at least 30% of the spinal cord injury subjects surveyed complained that, after injury, bowel and bladder dysfunction become a major problem. Many subjects felt that neurogenic bowel dysfunction caused problems that limited their normal daily activities, their social lives and made them more dependent on family and caregivers.

Chronic constipation and faecal incontinence have such a major impact on the victims of spinal cord injury that bowel management is extremely important[32]. Ideally the method employed to stimulate defaecation should be safe and inexpensive. It should accelerate colonic transit time at regular time intervals so that defaecation is predictable, effective and painless. There are several methods of stimulating defaecation. Amongst the most commonly used are fibre supplements, oral laxatives, suppositories, manual evacuation, and enemas. The spinal cord injury subjects usually use a combination of methods. No one particular regimen of methods is effective for all subjects and bowel management has to be individualised to the person[32].

Another means of managing bowel dysfunction is a colostomy. A colostomy, correctly sited, can simplify bowel care, save time, and allow the subject and the caregiver greater independence[34].

Research carried out by Stone et al[34] looked at the effectiveness of colostomy as well as the safety of this procedure when carried out on spinal cord injury patients with chronic gastrointestinal problems and perianal pressure abscesses. Unlike the general population, where a colostomy is usually performed for obstruction or perforation, in the spinal cord injury population colostomy is usually carried out for reasons such as difficulty with bowel evacuation, megacolon, incontinence and perianal pressure abscesses. Stone et al[34] sought to look at the effectiveness of, and the complications arising from colostomy performed for the aforementioned reasons in the spinal cord injury population.

Colostomy was performed on 20 spinal cord injury patients. The stoma site was determined by measuring total gut and segmental colonic transit times using radio-opaque markers. Patients that had difficulty with bowel evacuation but normal colonic transit benefited from a sigmoid colostomy. If there was decreased left colonic transit time then a right transverse colostomy was indicated. An ileostomy was performed on patients with dilated non-functional right colon.

The patients were asked to fill in a questionnaire about their "satisfaction" with the results of the colostomy. One patient died 15 days postoperatively from causes unrelated to the surgery, but none of the 19 living patients wanted to have their colostomy reversed. They all felt that their quality of life had been much improved. Stone et al[34] therefore concluded that colostomy is a safe, effective and well-accepted way of treating chronic gastrointestinal complaints and perianal pressure ulcers in spinal cord injury patients.

## INVESTIGATION OF COLONIC TRANSIT

The motility of the large bowel is probably the least understood of the segments of the gastrointestinal tract. Normal motility of the oesophagus, stomach and small bowel has been established but normal patterns of colonic motility vary considerably and are poorly defined. There are several methods for measuring colonic transit.

Mouth to anus transit can be assessed but this does not give any information on regional colonic transit. Regional colonic transit is of importance because the motility of the different segments of the colon is not coordinated.

Radiological investigations of the colon can also be carried out. One of these is cinefluorography of the colon to show motility and transit. This method is very informative but delivers a large radiation dose to the patient because of the prolonged imaging times needed to detect the infrequent movements of the colon[15]. Another method is the ingestion of radiopaque markers with sequential radiographs of the abdomen. This method is of great clinical value but has several disadvantages. Firstly, like cinefluorography it delivers a large radiation dose to the patient. The number of abdominal radiographs (5mSv per radiograph) that can be taken is therefore limited[36]. Secondly it does not give a dynamic picture of colonic activity. Thirdly the markers do not behave like a normal meal and they can stick in different sections of the colon for varying lengths of time. Lastly, the results are questionable in patients with severe constipation because in constipated patients the mass movements of the colon are decreased in frequency[16]. As abdominal radiographs of the markers are taken infrequently because of the radiation dose to the patient the method can give a misleading picture especially if radiographs are taken just before or just after a mass movement of the colon[16]. However it remains a good screening test for visualising and quantifying colonic transit and more importantly regional colonic transit.

Manometry is a well-validated non-imaging method of measuring colonic motility. It requires the insertion of a pressure sensitive device into the colon. It is invasive, and uncomfortable for the patient and does not correlate well with the movement of a meal through the colon[15, 16, 31, 36].

## SCINTIGRAPHY OF THE COLON

Scintigraphy of the colon has several advantages. It measures colonic transit physiologically, is non-invasive and patients find it tolerable[14]. Scintigraphy also enables the acquisition of multiple images without any increase in the radiation dose to the patient. The studies give precise, quantitative information on colonic transit, and it is possible to define the region of delayed colonic transit[15, 16, 23].

Because of the potential length of the study the radioactive label must have an adequately long physical half-life. The energy emission must lie within the range of gamma camera detection and must deliver a low radiation dose to the subject.

The estimated dose equivalent (EDE) to the whole body for a 7 day study using a meal or capsule labeled with 2MBq of Indium-111 ($^{111}$In) is 0.8mSv[36] and for a 10MBq dose it is 3.0mSv[16, 22, 23]. In comparison, two abdominal radiographs result in a dose of 10mSv[16, 23].

$^{111}$In has a half-life of 2.7 days (67 hours) and gamma emissions of 173 and 247 keV. The half-life of 67 hours makes $^{111}$In very suitable for long studies[37]. The other radionuclide suitable for long studies is Iodine-131 ($^{131}$I) but it has the disadvantage of having beta as well as gamma emissions and a half-life of 8 days (192 hours) that limit the dose that can be used. The dose to the colon, when using $^{131}I$, can be especially high in constipated subjects although the dose to the ovaries will be less than for radiopaque markers. In comparison with $^{131}I$, $^{111}In$ produces images of higher resolution and better counting statistics, and delivers lower radiation dose to the patient[38].

The two most commonly used radioisotope methods for examining colonic transit are the ingestion of a methacrylate-coated capsule containing $^{111}In$ labeled resin particles or the incorporation of $^{111}In$ labeled resin particles into a solid-phase meal. Both these methods have been well validated and both have advantages and disadvantages. The use of $^{111}In$ labeled IR-120 resin beads as a solid-phase marker was first developed by Mather et al[37]. Many other researchers have further validated the use of the $^{111}In$ Amberlite resin labeled pancake and the capsule[14, 15, 22, 36, 37, 39].

Both these methods use resin particles as the marker. The marker used for gastrointestinal labeling must fulfill certain criteria. It must remain confined to the lumen of the gastrointestinal tract and must not dissociate from the radioactive label. The particle must be inert, non-toxic, and non-digestible. Amberlite IR-120 cation exchange resin beads fulfill these criteria. The beads are spherical in shape and have a mean diameter of 0.7mm (range 0.5–1.0mm)[22]. They can be labeled with $^{111}In^{3+}$ trivalent cations that adhere well because of the size of their charge. The affinity of cations for Amberlite IR-120 resin in dilute acidic solution (0.04M HCl) depends on the size of their charge; therefore we have an affinity series of $m^{+} < m^{2+} < m^{3+}$. $^{111}In^{3+}$ is firmly bound to the resin and not exchanged in vivo[15, 16, 22, 37, 39, 40].

## $^{111}$In Amberlite resin capsule

In the method using a coated-capsule, the $^{111}In$ is absorbed onto Amberlite IR-120 resin. The capsule is coated with methacrylate that is designed to dissolve in the pH of the terminal ileum and therefore has the advantage of delivering a bolus of radioactivity in the region of the caecum. This makes it possible to do quantitative analyses of the colon without interference from small bowel activity and allows for the time of entry into the colon to be defined[15, 40]. However, in a series carried out by Proano et al[15] the capsules dissolved at different sites, varying from small bowel to transverse colon. Ideally the examination should mimic the transit pattern of food and this is not likely to occur with a capsule.

This technique of attempting to ensure the delivery of the radioisotope to the terminal ileum is unnecessary as the small variation in time taken for the food to reach the caecum and the interference of small bowel activity are of little importance when compared with the length of time taken to complete the study[23].

### $^{111}$In Amberlite resin pancake

The second method involves the use of $^{111}$In labeled Amberlite IR-120 resin to label a solid-phase meal. The resin is mixed uniformly in a test meal. The meal must fulfill certain criteria. It needs to be appetising and to approximate a normal meal in its total calorie content, and the proportion of fat, carbohydrate and protein. The meal also needs to be easy to reproduce. Reproducibility is essential as colonic transit times vary between individuals and it is important to keep variables to the minimum[15, 23].

There are certain advantages to incorporating the radiolabel into a meal. It means that gastric emptying, small bowel transit and colonic transit can be investigated in one study and the transit through the gastrointestinal tract represents the pattern of food[16].

## PATTERNS OF COLONIC TRANSIT

Notghi et al[14] established 5 distinct patterns of colonic transit which described normal excretion as taking place between 24 and 48 hours post ingestion. Van der Sijp et al[16] agreed with this time. The patterns of colonic transit as established by Notghi et al[14] will be used for diagnosis in this study and are as follows:

1. **RAPID TRANSIT:** The activity is distributed throughout the colon within 12 hours and most of the activity is excreted within 24 hours.
2. **INTERMEDIATE TRANSIT:** Most of the activity has accumulated in the caecum within 12 hours. The activity is excreted within 27 to 48 hours.
3. **GENERALISED DELAY:** There is no excretion of activity within 3 days, and the activity is distributed throughout the colon with no particular region of storage.
4. **RIGHT-SIDED DELAY:** There is no activity excreted within 3 days, and most of the activity remains in the ascending and transverse colon for this time.
5. **LEFT-SIDED DELAY:** The activity reaches the descending colon and rectum by 27 to 34 hours, but the activity remains in the rectosigmoid colon for 3 days with no faecal excretion.

Van der Sijp et al[16] carried out a comparison between radio-opaque markers and a radiolabelled meal in determining regional colonic transit and came to the conclusion that the radioisotope method could be regarded as reliable and the gold standard for measuring regional colonic transit because imaging could take place frequently in real time and the radiolabelled meal is physiologically incorporated into the gut content.

## PROCESSING AND PRESENTATION

A great deal of information is obtained from a scintigraphic colonic transit study, especially if the colon is divided into a large number of segments and regions of interest (ROI) are drawn around each one. Presenting and interpreting this can be difficult. Various methods of quantifying and presenting the results have been developed. Raw data can be displayed on film to visually assess the distribution of activity over time. This gives a good idea of overall transit. The ascending and transverse colons act as a reservoir and differ in function from the descending colon and rectosigmoid, which act as a conduit. It is therefore important to measure regional colonic transit as well as overall transit. ROIS can be drawn round prescribed segments of the colon in the anterior and posterior views for each time point and the geometric mean calculated for each time point. Geometric mean is used, and not the arithmetic mean, because of the exponential attenuation of the activity caused by the tissue of the subject[41]. The geometric mean accounts for the depth dependent variation in activity[38]. The variation caused by attenuation effects has been calculated to be 20%[39].

The geometric mean of the activity in each region as a percentage of the geometric mean of the initial total abdominal activity, at each time, can then be presented as a time-activity curve (percentage activity versus time) or as parametric images which show the movement, spread and progress of activity through each segment of the colon[14, 15, 36, 39].

The geometric mean activity can also be used to calculate the geometric centre at each time[14, 38, 39]. Geometric centre is a single figure that indicates "the region where 50% of the activity lies on either side". The geometric centre indicates the velocity of colonic transit[41]. It is suitable for use in trials that compare groups of subjects[14]. Delayed transit at a certain time point is indicated by a low value for geometric centre and similarly a high value for geometric centre indicates a rapid transit[41]. It has the disadvantage of not showing if the activity is fragmented in other regions of the colon or if it is traveling as a single bolus. Geometric centre also does not demonstrate the rate of movement through each segment. This can, however be shown very precisely on time-activity curves[16]. Retrograde movement can be missed on geometric centre. It still has, however, a valid role to play in comparing subjects and interpreting colonic transit results[14].

After correcting for decay, the percentage excreted can be calculated from the geometric mean of the total abdominal activity. A drop in the total abdominal activity is regarded as due to excretion[14].

The time-activity curve is one of the most commonly used methods of showing movement through the colon with time. More than one region can be shown on the same graph but this can become confusing if there are too many regions and it is simpler to present each region on a graph. One of the disadvantages of time-activity curves is that it makes the movement through the colon appear to be smooth but in actual fact it takes place by large infrequent movements. Also the time intervals between images are not constant and there is the long time interval during night when no imaging takes place[15, 16, 36].

## Assessment of the right and left colon

Because colonic motility is heterogeneous, it is necessary to assess the function of the proximal colon separately from the distal. Stivland et al[40] looked at the right colon transit by combining the ascending and transverse colon emptying times. They then compared this with the geometric centre, which they felt reflected overall transit. From this left colon function was estimated. However Notghi et al[14] disagree with this idea of geometric centre representing overall transit, especially in the individual, as they found large overlaps in geometric centre between different groups of patients which would limit the use of this method in determining the pattern of colonic transit in individual patients.

Proano et al[15] also looked at ascending colon transit. They evaluated the time at which all the activity appeared in the ascending colon (time zero). Then they observed the time at which the activity first appeared in the transverse colon. The difference between these two times was called the lag phase. The T½ of ascending colon emptying was obtained from the actual plot of the decay corrected time-activity curve, taking into account the time at which all the activity appeared in the ascending colon (time zero)[15].

# THE MAIN OBJECTIVES OF THE STUDY

The objectives of the study were to establish an effective technique for imaging, quantifying and presenting regional colonic transit for routine clinical studies, so that the effect of the level of spinal cord injury on colonic motility could be determined.

# MOTIVATION FOR STUDY

This research will contribute to the development of a method that can be used routinely in the Nuclear Medicine Department, Groote Schuur Hospital. It will establish whether there is a recognisable pattern of colonic transit associated with spinal cord injury and whether this pattern varies with the level of injury.

A stoma may provide an acceptable method of management of bowel function in spinally injured subjects. Unfortunately, stoma function in these individuals is unpredictable. This might be a result of poor understanding of colonic motility in these individuals.

# PATIENTS AND METHODOLOGY

## ETHICS

The Ethics Committee of the University of Cape Town approved this research. All subjects gave verbal informed consent after the procedure and the use of radionuclides was fully explained. The content of the consent form (shown in annexure A) was explained in detail to each subject. The forms were not signed because many of the paraplegics and all of the tetraplegics were unable to make a mark on paper unaided.

## INCLUSION CRITERIA

Two groups of subjects who had sustained permanent consequences of an acute episode of trauma to the spinal cord more than a year prior to the study were recruited. One group with complete injury above T1, and the other group with complete injury from below T1.

Eight paraplegic and eight tetraplegic subjects volunteered for the study. Seven lived in homes for the physically handicapped and 9 lived independently. Their motivation for participating in the study varied, some saw it as an outing to relieve boredom, some did it in the interest of research and others were interested in having a colostomy to simplify their bowel management.

## EXCLUSIONS

Subjects under the age of 18 and those who were pregnant were excluded. The study was restricted to subjects who had received traumatic injury to the spinal cord. Spinal cord injury for any reason other than trauma was excluded. In order to reduce the variables no subjects were accepted who had had previous surgery to their gastro-intestinal tract or who had other diseases that might alter gut transit such as diabetes, scleroderma, and inflammatory bowel disease.

## SUBJECT DISTRIBUTION

Five female and 3 male paraplegic subjects fulfilled the selection criteria. The mean age of the females was 47 years (range 34-61). The mean age of the males was 43 years (range 39 – 46). The mean age of all paraplegics was 45.5 years (range 34 –61). The mean time from injury for females was 15.4 years (range 7-23) and for males, 19.6 years (range 16 –23). There is no significant difference between male and female colonic transit times so these subjects will be regarded as a single group[39, 42]. As a group, the mean time from injury was 17 years (range 7-23). The level of injury for the paraplegic group ranged from T4 to T12, with T4 (n = 1), T5 (n = 1), T6 (n = 1), T7 (n = 1), T9 (n = 1), T12 (n = 3). The injuries were caused by motor vehicle accidents (n = 5), stab wound (n = 1), assault (n = 1) and spinal manipulation (n = 1). Five subjects were graded as A and 3 as B using the Frankel scale. Eight subjects were motor complete with 5 being sensory complete and 3 sensory incomplete.

The eight tetraplegics were all males. Their mean age was 31.6 years (range 21 - 44). The mean injury time was 8.8 years prior to this study (range 4-16). The level of injury was between C4 and C7 with C4 (n = 3), C5 (n = 2), C6 (n = 2) and C7 (n = 1). The injuries were caused by motor vehicle accidents (n = 4), rugby (n = 2), assault (n = 1) and a diving accident (n = 1). One subject was graded as A, 6 as B and 1 as C on the Frankel Scale. Seven were motor complete and 1 motor incomplete with 1 being sensory complete and 7 sensory incomplete. (Table 3)

**TABLE 3**

| Subject number | Age (years) | Sex | Years Post Injury | Cause of Injury | Level of Injury | Motor Complete | Sensory Complete | Frankel Scale |
|---|---|---|---|---|---|---|---|---|
| 1 | 50 | F | 13 | Stab | T7 | Yes | Yes | A |
| 2 | 39 | M | 16 | MVA | T9 | Yes | No | B |
| 3 | 34 | F | 12 | MVA | T5 | Yes | Yes | A |
| 4 | 45 | M | 23 | MVA | T12 | Yes | Yes | A |
| 5 | 61 | F | 7 | Manipulation | T12 | Yes | No | B |
| 6 | 43 | F | 22 | MVA | T12 | Yes | No | B |
| 7 | 46 | M | 20 | Assault | T4 | Yes | Yes | A |
| 8 | 46 | F | 23 | MVA | T6 | Yes | Yes | A |
| 9 | 21 | M | 4 | MVA | C4 | Yes | No | B |
| 10 | 34 | M | 5 | Assault | C6 | Yes | No | B |
| 11 | 27 | M | 8 | MVA | C4 | No | No | C |
| 12 | 29 | M | 7 | Diving | C7 | Yes | No | B |
| 13 | 27 | M | 6 | Rugby | C4 | Yes | No | B |
| 14 | 44 | M | 13 | MVA | C6 | Yes | Yes | A |
| 15 | 36 | M | 16 | MVA | C5 | Yes | No | B |
| 16 | 35 | M | 12 | Rugby | C5 | Yes | No | B |

*Subject details at the time of the study.*

## Subject preparation

Subjects were given an instruction sheet prior to the study (Copy in annexure A). They were requested to employ their usual method of bowel emptying, two days (Saturday) prior to commencement of the study. The most commonly used method of bowel management was a combination of sennoside tablets and bisacodyl suppositories (Table 4).

The subjects were asked not to eat or drink from 22h00 on Sunday except for a cup of tea or coffee at 06h00 on Monday.

The radiolabelled, standardised pancake plus 50-100 ml of water was given at 12h30 on the Monday. The subjects were not given any further food or liquid until after the 3 hour image. Thereafter the subjects could eat and drink freely.

**TABLE 4**

| Subjects | Living Conditions | Laxatives | Suppositories | Digital Manipulation | None |
|---|---|---|---|---|---|
| 1 | Independent | Yes | Yes | | |
| 2 | Independent | Yes | Yes | | |
| 3 | Independent | Yes | Yes | | |
| 4 | Independent | Yes | Yes | | |
| 5 | Home | Yes | Yes | Yes | |
| 6 | Independent | | | | Yes |
| 7 | Home | Yes | Yes | | |
| 8 | Home | | Yes | | |
| 9 | Independent | Yes | Yes | | |
| 10 | Home | Yes | Yes | | |
| 11 | Independent | | | | Yes |
| 12 | Independent | | Yes | | |
| 13 | Independent | Yes | Yes | | |
| 14 | Home | Yes | Yes | | |
| 15 | Home | Yes | Yes | | |
| 16 | Home | Yes | | | |

*Living conditions and bowel management.*

## PREPARATION OF $^{111}$IN AMBERLITE RESIN

- Weigh out 2g of Amberlite IR-120 resin into a 10ml stoppered glass vacuum tube.
- Add 4ml of 0.04M HCl.
- Mix manually for 1 minute.

- Centrifuge for 5 minutes at 2000 rpm.
- Carefully remove all supernatant liquid.
- Add a further 4ml of 0.04M HCl. Mix manually, centrifuge and remove supernatant as before.
- Repeat this washing procedure 5 times. Then remove all liquid from within the top volume of the resin slurry.
- Dispense 50mg of resin slurry into Greiner tubes with screw caps. One tube for each patient.
- Weigh each stoppered tube with contents.
- Add 10-18 MBq In-111-chloride after diluting tracer to required concentration with 0.04M HCl.
- Mix closed tubes for 30 minutes on rotary mixer. Then centrifuge for 5 minutes at 2000 rpm.
- Wash labeled resin twice with 0.04M HCl, centrifuging after each wash and discarding supernatant each time.

Because of the time required to wash the resin with the HCl the first 4 washes were carried out on the Friday preceding the investigation and the resin stored in the fridge until the Monday when the final 2 washes were performed just prior to the labeling process.

## MEAL CHARACTERISTICS[37]

492g total weight

27g fat

18g protein

625 calories

## PREPARATION OF $^{111}$IN LABELLED PANCAKE

### Ingredients:

57g flour

142g milk

14g oil

1 egg

- Blend the ingredients together to form a smooth batter.
- Pour 50 ml of the mixture into 50 ml polypropylene tube (Falcon).
- Empty the $^{111}$In labeled ion exchange resin into the pancake mixture in the Falcon tube and screw on cap.
- Shake to mix resin with batter then mix with the remainder of the pancake mixture.
- Preheat the microwave-browning dish in the microwave for 8 minutes.
- Grease browning dish and pour pancake mixture into the dish and cook in the microwave for 5 minutes on high[37].

## IMAGING PROTOCOL

A 40 centimeter field-of-view Elscint Gamma Camera with a medium energy collimator was used to acquire the images on a 256x256 matrix. Energy windows of 20% were set on the two energy peaks of $^{111}$In, 173 keV and 247 KeV.

Planar scintigrams were obtained for an acquisition time of 400 seconds in the anterior and posterior supine projections. Where it was not possible to acquire images for the full 400 seconds, counts were corrected for the time difference. Marker images were acquired in the same position with the xiphisternum and umbilicus being marked with a radioactive source. The initial images were acquired 3 hours after the ingestion of the pancake. All the activity within the entire abdomen was included within the field of view. Where this was not possible, two overlapping images were acquired. The subjects were allowed to go home each evening and return the following morning. In some cases it was easier to admit them to a ward for the duration of the study.

Anterior and posterior supine scintigrams were then acquired 3 times a day for the following 4 days at 08h30, 12h00 and 16h00. The investigation was terminated early if there was very little detectable activity left in the bowel.

## PROCESSING THE DATA

### Visual assessment

Hard copies were made of all raw data images. The time of imaging and orientation (anterior/posterior) of the image were clearly marked on each image.

Three Nuclear Medicine Physicians who were not given any clinical information were asked to independently, visually assess colonic transit from the anterior hard copy images. Each physician completed a tick sheet (Annexure A) for each subject. They classified transit into 5 patterns, namely rapid or intermediate transit, generalized delay or, right-sided or left-sided delay. The overall assessment was obtained by comparing the 3 assessments for each subject. When there was concordance that was accepted. When there was discordance, the majority assessment was accepted. A contingency correlation was used to measure the association between the 3 physicians assessments.

### Quantification

Seven regions of interest (ROIS) were drawn on both the anterior and posterior images outlining the following regions: (Figure 1)

1. Ascending colon (AC)
2. Hepatic flexure (HF)
3. Transverse colon (TC)

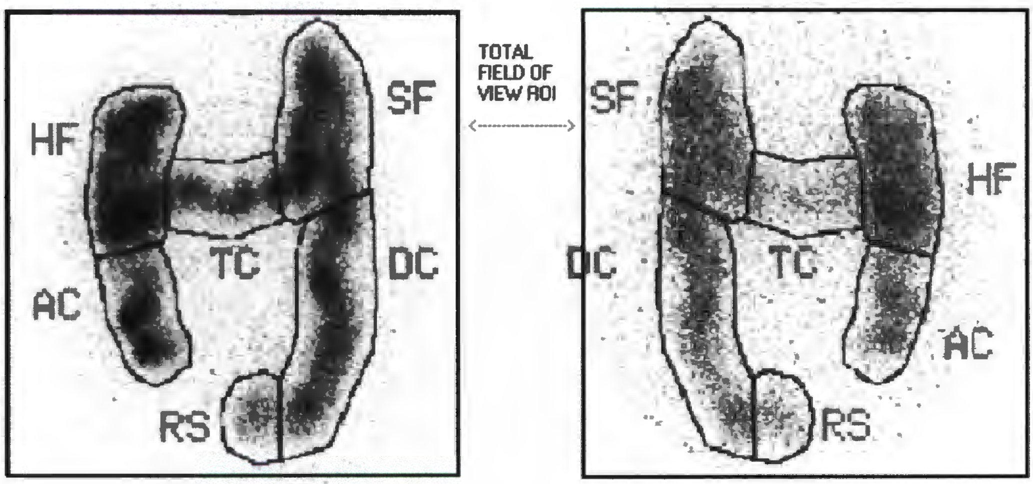
4. Splenic flexure (SF)

5. Descending colon (DC)

6. Rectosigmoid (RS)

7. Total activity in abdomen

**FIGURE 1**




*Anterior and posterior regions of interest.*

An artificial, 8th region was calculated to represent the percentage excreted. This was the percentage difference between the initial total field of view counts and the total field of view counts for time x. A difference greater than 10%, after correction for decay, was assumed to be due to faecal loss[14].(Annexure A)

1) The counts obtained in the ROIS were, where necessary, time corrected (TCC) to 400 seconds acquisition time:

   **TCC** = (Counts/Acq time) × 400

2) and then, corrected for decay (DCC) back to time 0:

   **DCC at Tt** = $Ct \times e^{+\lambda t}$

   DCC at Tt: Decay corrected counts at time t

   Ct: counts at time t

   e: base of the natural logs

   $\lambda = 0.693/67.4$ (t½ of $^{111}In = 67.4$ hours)

These corrected counts were used in all subsequent calculations.

3) The Geometric Mean (GM) for each region at each time point was calculated from the corrected counts in the anterior and posterior images:

   **GM** = SQRT((anterior counts × posterior counts))

4) The Geometric Centre (GC) of the isotope distribution was calculated using the GM as follows[43]:

$$\mathbf{GC} = \frac{(ROI1 \times 1) + (ROI2 \times 2) + (ROI3 \times 3) + (ROI4 \times 4) + (ROI5 \times 5) + (ROI6 \times 6) + (ROI7 \times 7))}{(ROI1 + ROI2 + ROI3 + ROI4 + ROI5)}$$

Where 1 = ascending colon, 2 = hepatic flexure, 3 = transverse colon, 4 = splenic flexure, 5 = descending colon, 6 = recto-sigmoid and 7 = excreted activity.

The GC was plotted on a graph as GC versus time using Microsoft Excel. The GC ranges were calculated for each time point in the 4 categories of colonic transit patterns found in the subjects, to identify a recognisable range for each pattern. The correlation coefficient between the GC at 75 hours and 98 hours, for the subjects imaged at both times, was calculated to see if there was a difference. The Mann Whitney U test was used to test the difference in the rate of transit in paraplegic and tetraplegic subjects. The GC mean arrival times and standard deviations for each subject group, for each colonic region were calculated and displayed graphically. A box and whisker plot was constructed to show the outliers in both groups.

5) The GM counts in each region for each time point were expressed as a percentage of the GM initial total abdominal counts as determined from the 3 hour image.

**% Activity** = (GM of colon segment counts/GM initial total abdominal counts) x 100.

Parametric images were constructed using the % activity for each region versus time. The % activity was plotted on the y-axis (grey scale) versus the time in hours on the x-axis. Hard copies were taken. These were visually assessed.

The right colon and left colon were assessed separately. The right side was defined as the ascending colon, hepatic flexure, and transverse colon. The left side of the colon was defined as the splenic flexure, descending colon, and rectosigmoid. The % activity in these regions for each side, for each time point, was combined. Time-activity graphs were constructed using Microsoft Excel.

The median arrival and clearance times were calculated for the right and left colon, for each group, for 74 and 96 hours. The Kruskal-Wallis analysis of variance was used to compare the transit through the right and left colons, between the two groups. Activity was considered to have entered the right side of the colon when the activity in the right side of the colon exceeded 10% of the total abdominal activity. Similarly, the time of entry into the left side of the colon was determined when more than 10% of the total abdominal activity had entered the left side of the colon. Activity was considered to have cleared from the relevant side of the colon when the activity had dropped to less than 10% of the total abdominal activity. This allowed assessment of the different functions of the two sides of the colon.

The four methods of evaluating colonic transit (analogue images, geometric centre, parametric images and right side versus left side of the colon) were assessed independently. The results were tabulated. When there was concordance it was accepted. When there was discordance, the majority assessment was accepted.

## Statistical analysis

The contingency coefficient was used to measure the extent of association between the reports of the 3 Nuclear Medicine Physicians because the information was categorical and non-parametric.

The Mann Whitney U Test was used to compare the difference between the geometric centre of the paraplegic and tetraplegic groups because the data was regarded as non-parametric in nature. Variances were found to be non-homogeneous using the Cochran test.

The mean arrival times and standard deviations of the geometric centre of the paraplegic group and the tetraplegic group, for each time point were calculated and plotted on a graph[14].

A box and whisker comparison between paraplegic and tetraplegic geometric centres mean transit times was plotted to examine outliers in both groups.

The median imaging times and quartile deviation were calculated for each group because of the non-parametric nature of the data. The median and quartile deviation were calculated for the comparison between arrival and departure times of the activity in the right colon and left colon.

The Kruskal-Wallis analysis of variance was used to compare the transit through the right and left colons, between the two groups, because of the non-parametric nature of the data.

The Fisher exact probability test was used to compare the frequency with which the paraplegic and tetraplegic groups fell within each category of colonic transit. The Fisher exact test was used because of the nonparametric nature of the data and the small sample size.

# RESULTS

Detailed information on each subject is given in Annexure B, as a short case history, the analogue images, geometric centre against time, a parametric image and a time-activity curve of activity in the right and left sides of the colon.

The images taken are summarized in Table 5. There was deviation from the planned imaging time for logistical reasons. All subjects were imaged on day 1. The majority of subjects were imaged 3 times a day on days 2, 3 and 4. Only half the subjects attended on day 5 because of transport problems on Fridays.

**TABLE 5**

| Day | Planned time of imaging (hours) | Median time of images (hours) | qdev | Patients (n) |
|---|---|---|---|---|
| 1 | 3 | 3.50 | 0.625 | 16 |
| 2 | 20 | 20.50 | 1.5 | 15 |
| 2 | 24 | 24.00 | 1.5 | 15 |
| 2 | 27 | 27.50 | 0.875 | 16 |
| 3 | 44 | 44.50 | 1.125 | 15 |
| 3 | 48 | 48.50 | 1.0 | 16 |
| 3 | 51 | 51.25 | 0.5 | 14 |
| 4 | 69 | 68.25 | 1.0 | 16 |
| 4 | 72 | 72.00 | 1.25 | 10 |
| 4 | 75 | 74.50 | 1.0 | 16 |
| 5 | 92 | 92.25 | 0.625 | 8 |
| 5 | 96 | 95.50 | 1.0 | 5 |
| 5 | 98 | 98.50 | 1.0 | 8 |

*The median and quartile deviation (qdev) of the times that imaging actually took place each day, is shown with the number of subjects imaged at each session.*

One hundred and seventy-two anterior images were acquired during the course of the entire trial. Of these, 139 were acquired for the prescribed 400 seconds, 16 were acquired for 300-389 seconds, 13 for 200-286 seconds and 4 for less than 200 seconds. An equal number of posterior images were acquired, 152 for the full 400 seconds, 7 for 300-377 seconds, and 7 for 200 seconds. The main reason for terminating the acquisition early was spasm. Many of the subjects experienced severe spasms whilst lying on the scanning table. This caused movement on the images. The imaging was stopped as soon as these spasms occurred. Some of the subjects became distressed when lying flat and these images were also terminated early. When all the activity in the abdomen could not fit within the field of view of the gamma camera then two images were acquired for 200 seconds each. This occurred in two subjects. Most of the images that were terminated early occurred on the first full day of scanning (20, 24,and 27 hours) (Table 6). This may have been due to the subjects feeling nervous about the study and the movement from wheel chair to scanning bed and back.

## TABLE 6

| Time | Subject 1 | Subject 2 | Subject 4 | Subject 3 | Subject 5 | Subject 6 | Subject 7 | Subject 8 | Subject 9 | Subject 10 | Subject 11 | Subject 12 | Subject 13 | Subject 14 | Subject 15 | Subject 16 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *(h)* | *(sec)* | *(sec)* | *(sec)* | *(sec)* | *(sec)* | *(sec)* | *(sec)* | *(sec)* | *(sec)* | *(sec)* | *(sec)* | *(sec)* | *(sec)* | *(sec)* | *(sec)* | *(sec)* |
| 3 | 200 | 300 | 400 | 191 | 303 | 200 | 198 | 400 | 200X2 | 188 | 400 | 400 | 382 | 141 | 300 | 400 |
| 20 | 341 | 400 | 400 | 400 | 400 | 400 | 400 | 400 | 200 | 400 | | 400 | 225 | 400 | 400 | 400 |
| 24 | 270 | 400 | 400 | 331 | 400 | 332 | 400 | 400 | 400 | 400 | 273 | 400 | 310 | 386 | 400 | 384 |
| 27 | 382 | 400 | 400 | 200x2 | 400 | 341 | 400 | 400 | 200 | 300 | 286 | 400 | 339 | 400 | 300 | 400 |
| 44 | 400 | 400 | 400 | 400 | 400 | 400 | 400 | 400 | 400 | 400 | | 400 | 400 | 400 | 400 | 400 |
| 48 | 400 | 400 | 400 | 400 | 400 | 400 | 400 | 400 | 400 | 400 | 400 | 400 | 344 | 400 | 400 | 389 |
| 51 | 400 | 400 | 400 | 400 | 211 | 400 | 400 | 400 | 400 | | 400 | 400 | 400 | 400 | | 400 |
| 69 | 400 | 400 | 400 | 400 | 400 | 400 | 400 | 400 | 400 | 400 | 400 | 400 | 400 | 400 | 400 | 400 |
| 72 | 400 | | 400 | | | 400 | 400 | 400 | | 400 | | | 400 | 400 | 400 | 400 |
| 75 | 400 | 400 | 400 | 400 | 400 | 400 | 400 | 400 | 400 | 400 | 400 | 400 | 400 | 400 | 400 | 400 |
| 92 | 400 | | 400 | 200 | 400 | 400 | | | 400 | | | | 400 | 400 | | |
| 96 | 400 | | 400 | | | 400 | | | | | | | 400 | 400 | | |
| 98 | 400 | 400 | | 400 | 400 | 400 | | | 400 | | | | 400 | 400 | | |

*Anterior image acquisition times for all subjects.*

## Visual assessment

The result of the 3 Nuclear Medicine Physicians visual assessment of the anterior analogue images for each subject, according to the prescribed pattern of colonic transit is shown in Table 7.

**TABLE 7**

| Subject | Physician 1 | Physician 2 | Physician 3 | Overall assessment |
|---|---|---|---|---|
| 1 | Gen delay | Gen delay | L-sided delay | Gen delay |
| 2 | R-sided delay | Gen delay | R-sided delay | R-sided delay |
| 3 | R-sided delay | Gen delay | R-sided delay | R-sided delay |
| 4 | R-sided delay | R-sided delay | R-sided delay | R-sided delay |
| 5 | R-sided delay | L-sided delay | R-sided delay | R-sided delay |
| 6 | R-sided delay | R-sided delay | R-sided delay | R-sided delay |
| 7 | R-sided delay | Gen delay | R-sided delay | R-sided delay |
| 8 | Intermediate | Gen delay | Intermediate | Intermediate |
| 9 | Gen delay | Gen delay | L-sided delay | Gen delay |
| 10 | L-sided delay | Gen delay | L-sided delay | L-sided delay |
| 11 | Intermediate | Intermediate | Intermediate | Intermediate |
| 12 | Intermediate | Intermediate | Intermediate | Intermediate |
| 13 | L-sided delay | Gen delay | L-sided delay | L-sided delay |
| 14 | Gen delay | L-sided delay | L-sided delay | L-sided delay |
| 15 | Gen delay | Gen delay | L-sided delay | Gen delay |
| 16 | Gen delay | L-sided delay | L-sided delay | L-sided delay |

*The assessment of each physician is shown in the $2^{nd}$ to $4^{th}$ columns. The $5^{th}$ column shows the assessment of 2 or more of the physicians.*

The contingency coefficient shows that the correlation between physicians 1 and 3 (0.81) is significant ($p<0.001$).

## Geometric centre

Table 8 shows the range of the geometric centres for each colonic transit pattern for each time point. The more rapid transit of the intermediate group is clearly seen by 24 hours. At 48 hours the geometric centre range for the intermediate group is 6.7-6.8. At 24 hours there is considerable overlap of the geometric centre ranges for all the delayed patterns. Between 44 and 51 hours the range for the left-sided delay group is 3.2 – 5.6, but after that it overlaps with the other delayed groups at the lower end of the range. This overlapping of the ranges for all the delayed groups appears and disappears at different times throughout the study. There is a consistent overlap between the generalised delay and the right-sided delay.

**TABLE 8**

| | INTERMEDIATE TRANSIT | GENERALISED DELAY | RIGHT SIDE DELAY | LEFT SIDE DELAY |
|---|---|---|---|---|
| *TIME (H)* | *RANGE* | *RANGE* | *RANGE* | *RANGE* |
| 3 | 0.0-0.6 | 0.0-0.0 | 0.0-0.0 | 0.0-0.0 |
| 20 | | 0.6-1.7 | 1.5-2.4 | 1.2-2.8 |
| 24 | 4.3-4.9 | 0.8-2.2 | 1.6-2.5 | 1.8-2.5 |
| 27 | 4.3-4.9 | 0.9-2.3 | 1.6-2.7 | 2.4-4.1 |
| 44 | | 1.9-3.1 | 1.9-3.2 | 3.2-5.4 |
| 48 | 6.7-6.8 | 2.2-2.5 | 2.1-3.0 | 3.2-5.4 |
| 51 | 6.7-6.8 | 2.3-2.4 | 1.9-3.2 | 3.2-5.6 |
| 69 | 6.8-6.9 | 3.1-3.6 | 2.6-3.7 | 3.4-5.7 |
| 72 | | | | 3.3-5.6 |
| 75 | 6.8-6.9 | 3.4-3.8 | 2.5-3.9 | 3.3-5.7 |

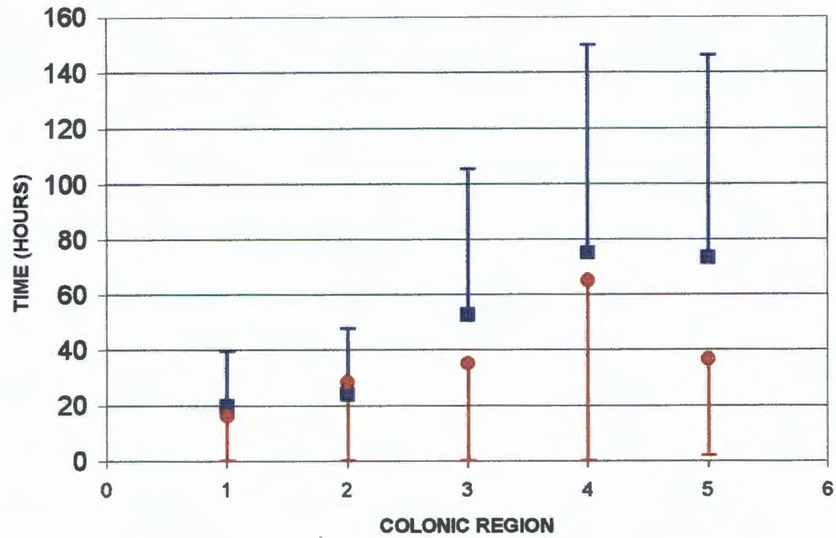
*Geometric centre ranges for different patterns of colonic transit for all subjects at varying time intervals.*

Eight of the 16 subjects were imaged for 98 hours. In these 8 subjects, there was a significant correlation between the geometric centres at 75 hours and 98 hours (correlation coefficient =0.91).

Using geometric centres, no difference in the rate of transit in paraplegic and tetraplegic subjects was demonstrated (p=ns).

The mean arrival times and standard deviations of the geometric centre in each segment of the colon for each group are shown in Graph 1.

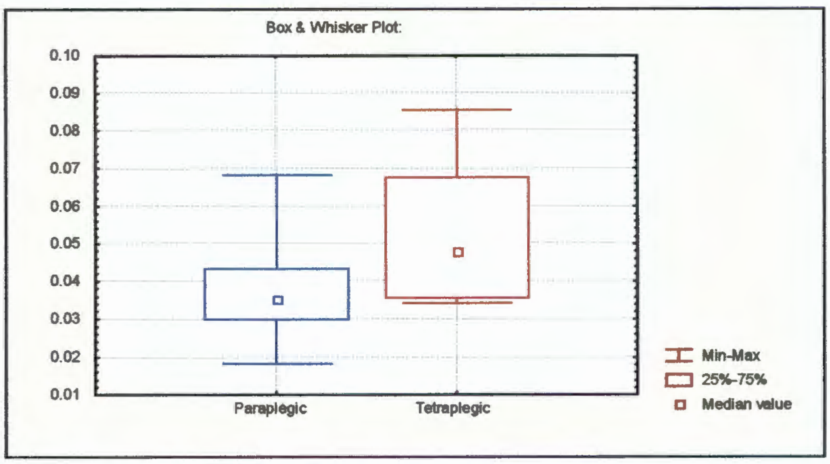
**GRAPH 1**




*The geometric centre, mean arrival times and standard deviations of the paraplegic group (n=8) (■) and the tetraplegic group (n=8) (●) for each colonic region.*

Graph 2 shows the box and whisker comparison of the geometric centre mean transit times for the two groups. Outliers are seen in both groups.

**GRAPH 2**




*A box and whisker comparison between paraplegic (1) (n=8) and tetraplegic (2) (n=) geometric centre, mean transit times, show outliers in both groups. These subjects are discussed in Annexure B.*

## Parametric images

The movement of the activity through the colon could be clearly seen on the parametric images. In all but one of the subjects, movement took place between the late afternoon image and the early morning image of the following day. Movement of the activity through the ascending colon, hepatic flexure, transverse colon, splenic flexure and descending colon takes place between the 19 hour, 24 hour and 28 hours images (day 2) in subject 13.

Excretion was seen on the parametric images of four paraplegic subjects (23% excretion at 22 hours in one, 14% at 68.5 hours in the second, 17% at 45 hours in the third, and 29% at 44.5 hours in the fourth).

Four tetraplegic subjects showed excretion (93% of the activity at 44 hours in one, 96% at 47.5 hours in the second, 21% at 68 hours in a third, 12% at 75 hours in the fourth).

## Right side versus left side of the colon

The arrival time and clearance of activity in the right colon and clearance in the left colon of paraplegic and tetraplegic subjects was similar. Activity arrived earlier in the left colon in tetraplegic subjects when compared to paraplegic subjects ($p = 0.04$). (Table 9)

The median arrival time of activity in the right side of the colon in paraplegic subjects was 20.25 hours (qdev 0.875). The median time at which activity cleared from the right side of the colon, was 74.25 hours (qdev 6.5). In tetraplegic subjects the median arrival time was 21 hours (qdev 1.5) and cleared by 74.5 hours (qdev 35.5).

The median arrival time of activity in the left side of the colon in paraplegic subjects was 44.25 hours (qdev 14.875) and activity was cleared by 74.5 hours (qdev 0.625). The median arrival time of activity in the left side of the colon in tetraplegic subjects was 23 hours (qdev 6) and activity was cleared by 74.75 hours (qdev 12.25).

**TABLE 9**

| | | Paraplegic | Tetraplegic | p |
|---|---|---|---|---|
| Right colon | Arrival (hrs) | 20.25 (0.875) | 21 (1.5) | NS |
| | Clearance (hrs) | 74.25 (6.5) | 74.5 (35.5) | NS |
| | | | | |
| Left colon | Arrival (hrs) | 44.25(14.875) | 23 (6) | 0.04 |
| | Clearance (hrs) | 74.5 (0.625) | 74.75 (12.25) | NS |

*Median (qdev) arrival and clearance times (hrs) in the right and left colon*

## Comparison of the four methods of assessment

The result of each method of assessment of transit per subject is shown in Table 10.

**TABLE 10**

| Subjects | Physicians assessment | Geometric centre | Parametric images | R side vs L side | Final categorisation |
|---|---|---|---|---|---|
| 1 | Gen delay | Gen delay | Gen delay | Gen delay | Gen delay |
| 2 | R delay | R delay | R delay | R delay | R delay |
| 3 | R delay | Gen delay | Gen delay | Gen delay | Gen delay |
| 4 | R delay | R delay | R delay | R delay | R delay |
| 5 | R delay | R delay | R delay | R delay | R delay |
| 6 | R delay | R delay | R delay | Gen delay | R delay |
| 7 | R delay | L delay | L delay | L delay | L delay |
| 8 | Intermediate | L delay | L delay | L delay | L delay |
| 9 | Gen delay | Gen delay | Gen delay | Gen delay | Gen delay |
| 10 | L delay | R delay | L delay | L delay | L delay |
| 11 | Intermediate | Intermediate | Intermediate | Intermediate | Intermediate |
| 12 | Intermediate | Intermediate | Intermediate | Intermediate | Intermediate |
| 13 | L delay | L delay | L delay | L delay | L delay |
| 14 | L delay | L delay | L delay | L delay | L delay |
| 15 | Gen delay | R delay | L delay | L delay | L delay |
| 16 | L delay | L delay | L delay | L delay | L delay |

*Categorisation of each subject according to each method. The final categorisation, which is the majority decision, is shown in the last column.*

The agreement between the four methods of assessment is presented in Table 11. The best agreements occur between the quantitative methods and not the observer.

TABLE 11

| | Physicians | Geometric centre | Parametric images | Right and left colon |
|---|---|---|---|---|
| Physician | | 11 | 12 | 11 |
| Geometric centre | 11 | | 14 | 13 |
| Parametric images | 12 | 14 | | 15 |
| Right and left colon | 12 | 13 | 15 | |

*An agreement matrix that compares the number of agreements between the four methods of assessment in the 16 subjects.*

## Level of injury versus colonic transit

The level of spinal cord injury found in each pattern of colonic transit is summarised in Diagram 3. None of the subjects in this study had rapid transit. Two tetraplegic subjects fell within the normal range (intermediate) of colonic transit. Two paraplegic subjects and one tetraplegic subject had generalised delay. Right-sided delay was found in 4 paraplegic subjects. Left sided delay occurred in 2 paraplegic and 5 tetraplegic subjects. There was significantly more right sided delay in paraplegics ($p=0.04$)(Table 12).

## DIAGRAM 3

| Spinal Level | Intermediate | Right-sided Delay | Left-sided Delay | Generalised Delay |
|---|---|---|---|---|
| C1 | | | | |
| C2 | | | | |
| C3 | | | | |
| C4 | ● | | ● | ● |
| C5 | | | ●● | |
| C6 | | | ●● | |
| C7 | ● | | | |
| T1 | | | | |
| T2 | | | | |
| T3 | | | | |
| T4 | | | ● | |
| T5 | | | | ● |
| T6 | | | ● | |
| T7 | | | | ● |
| T8 | | | | |
| T9 | | ● | | |
| T10 | | | | |
| T11 | | | | |
| T12 | | ●●● | | |

*The level of spinal cord injury found in each category of colonic transit presented as a diagram.*

## TABLE 12

| | INTERMEDIATE TRANSIT | GENERALISED DELAY | RIGHT-SIDED DELAY | LEFT-SIDED DELAY |
|---|---|---|---|---|
| PARAPLEGICS | 0 | 2 | 4 | 2 |
| TETRAPLEGICS | 2 | 1 | 0 | 5 |

*The pattern of colonic transit in paraplegic and tetraplegic subjects presented as a Table.*

# DISCUSSION

The results show that the level of spinal cord injury affects the pattern of colonic transit (Diagram 3). Injuries below T7 have right-sided delay, while those above T7 are most likely to have left-sided delay. Paraplegics are more likely to have right-sided delay ($p=0.04$) and tetraplegics, left-sided. Some injuries above T7 are associated with either intermediate transit or generalized delay. There was some overlap between the cervical spine injuries and the upper thoracic spine injuries in the generalised and left-sided delay categories.

This study set out to establish whether the colonic transit in tetraplegic subjects differed from that of paraplegic subjects. This has been demonstrated. It appears, however, the division is not one of paraplegia versus tetraplegia. The level of injury at which the difference in the colonic transit occurs is T7 or T8 and not T1. More subjects should be studied to confirm this level.

This study agrees with that carried out by Beuret-Blanquart et al[44]. They considered cervical and thoracic injuries above T9 as a group. Colonic transit time was calculated using radiopaque markers. Gore and Mintzer[26] state that subjects with cervical or thoracic lesions have proximal faecal impaction. They do not give any indication as to how they arrived at this conclusion. Our results showed that injuries from T9 and below had proximal delay whereas above T9 the delay tended to be distal. Menardo et al[31] used radiopaque markers and daily abdominal xrays to measure colonic transit. They found that the level of spinal cord injury did not influence colonic transit and that subjects with injuries above the lumbosacral outflow all had slow transit but that the site of delay varied. They found no discernable pattern. However, Keshavarzian et al[39] who used $^{111}$In Amberlite resin capsules to assess colonic transit, found that subjects with spinal cord injuries at or below T9 had slower transit through the right side of the colon.

Many theories have been advanced as to the effect of spinal cord transection on colonic transit. Beuret-Blanquart et al[44] found that transit through the right and left colon was unaffected by spinal cord lesions, and that total colonic transit and rectosigmoid transit times were increased. They conclude that the extrinsic nervous system plays an important role in colonic transit and that the nervous control of the spinal cord affects the distal and not the proximal colon. Keshavarzian et al[39] demonstrated delayed colonic transit in both the right and left side of the colon and an increased overall transit time. They felt that any transit delay was not due to faecal impaction because their subjects continued to use their bowel cleansing treatment throughout the study. Menardo et al[31] found that right-sided delay was not as a result of blockage in the left side of the colon and that transit through the left colon was much slower than that through the right side. Stone et al[34] divided subjects with spinal cord lesions and gut dysfunction into two groups, those with failure of the colon to propel faeces, and those who had normal colonic propulsion but were unable to empty their rectums. However Stone et al[34] did not investigate the level of the spinal lesion. Gore et al[26] states that gastrointestinal complications more commonly occurred in subjects with cervical and upper thoracic spinal cord injuries than in those with lower thoracic or lumbar injuries. They postulate that the parasympathetic innervation of the colon usually remains intact after injury but that the sympathetic innervation is lost especially if an injury occurs above T4-T6.

Subjects with cervical and upper thoracic spinal cord injury will still have the parasympathetic nervous innervation to the foregut via the intact vagus nerves. The parasympathetic innervation to the hindgut will still be present via the hypogastric reflex arc and the pelvic nerves. The sympathetic nervous innervation of the entire gut via reflex arcs will be present. Parasympathetic connections from the hypogastric plexus and all sympathetic connections to the brain are lost. There will be an imbalance of the autonomic nervous system. The intrinsic nervous system remains intact. Voluntary control of defaecation is lost and the external anal sphincter may be spastic. The cord mediated reflex for defaecation may be blocked or altered. Subjects become constipated because of evacuation inertia.

Our results show that transit through the colon can be normal, or it can be slow without any segmental hold up. When hold up does occur, it is left-sided. The normal transit may be as a result of the loss of the inhibitory effect of the sympathetic nervous system. The parasympathetic and intrinsic nervous systems propel the stool towards the anus. In the two subjects in our study who had normal transit and evacuation the cord mediated reflex for defaecation was functional.

The tetraplegic group had a significantly earlier arrival time of the activity in the left side of the colon. They also had significant left sided delay. The transit through the colon, propelled by unopposed parasympathetic nervous stimulation moved the stool through the right side of the colon but because of the spasticity of the external anal sphincter or the loss of the defaecation reflex the stool remained within the left side of the colon.

Subjects with lower thoracic spinal cord injuries will have intact sympathetic activity in the entire gastrointestinal tract. The parasympathetic activity in the left colon is however altered by loss of the central input to the hypogastric plexus. This results in a hypodynamic left colon. This translates into right-sided delay on imaging.

Four different methods were used to assess colonic transit to reduce the error in categorizing subjects into one of 5 patterns of colonic transit. These methods are complementary and no one method completely characterised the colonic transit in a particular subject (Table 11). The visual analysis was carried out on the analogue images and was dependent on the observers' expertise. The other 3 methods all involved quantitative analysis of the data. Table 11 shows that the best agreement was reached between the parametric images and the comparison between arrival and clearance times in the right and left colons. This is to be expected as both the graphs were constructed from the % activity in each segment of the colon for each time point. The difference lay in how the data was used. The parametric images were constructed using % activity in each segment of the colon on the y-axis versus time (hours) on the x-axis. The time-activity graph showing the arrival and clearance of the activity in the right and left sides of the colon was constructed using the sum of the % activity in the ascending colon, hepatic flexure and transverse colon for the right side of the colon and the sum of the splenic flexure, descending colon and rectosigmoid for the left side. Table 11 also shows good agreement between the geometric centre and parametric images. Like the parametric images geometric center is derived from the counts in each segment of the colon for each time point.

Movement of colonic contents takes place as a series of infrequent mass movements. Only a rough estimate of colonic transit can be made if the subjects are not imaged for long enough and at infrequent intervals[39]. Very few radionuclide colonic transit studies have been carried out on spinal cord injured subjects. Keshavarzian et al[39] imaged colonic transit in 7 subjects with injury below T1, with a radiolabelled capsule, 3 times a day for 3 days. Menardo et al[31] followed the movement of radiopaque markers through the colons of 11 paraplegics, for up to 7 days. These subjects had an abdominal x-ray once a day. Van der Sijp et al[16] and Proano et al[15] both compared the colonic transit of radiopaque markers with radionuclide investigation of colonic transit on healthy volunteers and severely constipated subjects. They found that infrequent radiographs could be misleading and that the radiopaque marker method results were consistently faster than the radionuclide method. In this study, subjects were scanned once on the day of ingesting the pancake and three times a day for the next 4 days (98 hours). The study was terminated early if the bulk of activity was excreted or if the subject was unable to attend on the final day. All subjects were imaged for a minimum of 75 hours. The geometric center at 75 hours was compared with the geometric center at 98 hours of the same subject. The arrival and clearance times in the right and left colon were also compared at 75 and 98 hours of the same subjects. There was little difference in 75 and 98-hour geometric centres and the right and left arrival and clearance times. The study could be terminated at 75 hours without significant loss of data.

Patient preparation always took place over the weekend. The study always started on a Monday because imaging could then continue for 5 days. Markers were abandoned on some subjects, as they did not help with positioning the ROIS and lengthened the scanning time considerably, causing unnecessary distress. The transverse colon, in particular changed position and shape each time some subjects were moved and made the markers redundant. Most of the large bowel movement and evacuation happened between 17:00 and 9:00 the following day, at a time when it was difficult to image the subjects. None of the subjects in this study were imaged during the night. Any colonic movement during this time-period was assumed from the difference between the late afternoon image and the early morning image of the following day.

The biggest problem encountered when processing the data was identifying the different segments of the colon. The superimposition of the various segments caused a problem when drawing the ROIS. This most commonly occurred at the flexures where the hepatic flexure, transverse colon and even ascending colon could be superimposed one upon the other, or similarly the splenic flexure, transverse colon and descending colon. In these instances all superimposed segments were included in the relevant flexure ROI. The counts in this combined ROI caused the % activity in the flexures to be artificially raised.

The total counts, in each image for each time, were always corrected for decay and where necessary for acquisition time. In theory, these should have remained constant unless excretion had taken place. In practice this did not occur, the counts decreased over time. Excretion was considered to have taken place if the difference in counts between the initial total field of view counts and the total field of view counts for time x differed by >10%. The decrease in counts could have been due to the change in distribution of the activity within the field of view or to attenuation not wholly corrected for by the geometric mean. Another reason for this discrepancy may be that the subject regarded his/her faecal loss as negligible so didn't mention it. It may be that for all of the above reasons the use of a difference in counts of >10% as evidence of excretion may be too low. Of the 4 paraplegic subjects who had evidence of excretion on the parametric images, only one admitted to having excreted, no activity ever appeared in the descending colon or rectosigmoid of two of them, and the fourth subject was absolutely adamant that no excretion took place. Of the 4 tetraplegics who had evidence of excretion, two definitely excreted and two had activity in the rectosigmoid but denied having excreted.

The geometric centre was not reliable in identifying delayed colonic transit patterns in individual subjects. The geometric centre can be misleading if:

1. The splenic flexure overlies the distal part of the transverse colon and the proximal part of the descending colon so that the activity in the splenic flexure is artificially high.

2. The activity divides into two parts with one at the hepatic flexure and the other at the splenic flexure (regions 2 and 4). The geometric centre will fall within the transverse colon (region 3).

3. The activity is equally divided between all the regions of the colon. The geometric centre will appear to be within the transverse colon (region 3).

At varying times the geometric centre range (Table 8) overlapped for all the delayed categories. This sometimes made the categorisation of individual subjects by geometric centre alone inaccurate but it was very useful in comparing the rate of colonic transit between the two groups.

Five subjects elected to have colostomies. The site of the colostomy was determined by the colonic transit study. Two paraplegic subjects had the colostomy sited in the right transverse colon, as their colonic transit study indicated right-sided delay. Three tetraplegics had colostomies, two sited in the sigmoid and one in the right transverse colon. One of the tetraplegics with the sigmoid colostomy had generalised delay and the other, intermediate transit. The tetraplegic with the right transverse loop colostomy had left sided delay with retrograde movement back into the ascending colon on day 5.

# CONCLUSION

There was no complete agreement between the four methods of assessment therefore, one method used in isolation is not recommended. Visual assessment of the analogue images provides a general overview of colonic transit. A combination of the analogue images and 2 quantitative methods seems to provide the best option for evaluating colonic transit.

Colonic transit differs depending on the level of spinal cord injury. Injuries below T7/T8 result in right-sided delay. Injuries above this most commonly result in left-sided delay and occasionally in either normal transit or generalized delay.

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44. Beuret-Blanguart F, Weber J, Gouverneur JP, Demangeon S, Denis P. Colonic transit time and anorectal manometric anomalies in 19 patients with complete transection of the spinal cord (abstract only journal not available). *J Auton Nerv Syst.* 1990;**30**:199-207.

# ANNEXURE A

## Consent

Name__________________________

People who have had a spinal injury are troubled by the loss of control of their bowel. Not only do they have difficulty achieving a bowel action but they also have problems keeping themselves clean. Many patients complain of constipation. One of the reasons for this may be a change in how the colon functions.

We wish to study how contents moves through your bowel. We do this by giving you a meal of a pancake containing a radio-isotope that we can track with a special camera. Pictures will be taken early in the morning and in the late afternoon until you have passed all the radio-isotope or for a maximum of five days. The procedure is entirely painless and you will not need to be admitted to hospital. The amount of radio-activity to which you will be exposed is less than a standard series of X-rays.

Signature ______________________ Date __________

Witness ______________________

## PRE-SCAN INSTRUCTIONS

Please use your usual method of bowel evacuation on the Saturday prior to the study.

Do not eat or drink after 22h00 on Sunday.

At 6h00 on Monday you may have a cup of tea or coffee to drink.

Please arrive in C3, Nuclear Medicine Department at 11h00 on Monday morning.

You will be given a standardised pancake labelled with $^{111}In$ Amberlite resin to eat followed by 100 ml of water.

Imaging will commence 3- 4 hours later after which you may eat and drink normally.

No aperients or enemas are permitted during the imaging period of 5 days.

## COLONIC TRANSIT ASSESSMENT SHEET

1. **RAPID TRANSIT**: Bulk of activity excreted within 24 hours
2. **INTERMEDIATE TRANSIT**: Bulk of activity excreted within 48 hours
3. **RIGHT-SIDED DELAY:** No excretion taken place. Bulk of activity held up in ascending and transverse colon.
4. **LEFT-SIDED DELAY:** No excretion taken place. Bulk of activity held up in descending and Recto/sigmoid colon.
5. **GENERALISED DELAY:** No excretion taken place. No regional colonic hold-up. Generalised slow transit through the colon.

### Subject no:

Tick the relevant block:

☐ Rapid transit

☐ Intermediate transit

☐ Right-sided delay

☐ Left-sided delay

☐ Generalised delay

Comments:

# COLONIC TRANSIT STUDY

DATASHEET 1 (COLON1)

**Patient:** Subject 14

**Folder #:**

| TIME OF IMAGING (Hours) | ACQ DURATION | TOTAL COUNTS ANTERIOR | REGION AREA | ACQ DURATION | TOTAL COUNTS POSTERIOR | REGION AREA |
|---|---|---|---|---|---|---|
| 3 | 141 | 314873 | 65536 | 400 | 204662 | 65536 |
| 20 | 400 | 741009 | 65536 | 400 | 203409 | 65536 |
| 23.5 | 386 | 693209 | 65536 | 400 | 186304 | 65536 |
| 27 | 400 | 607264 | 65536 | 400 | 217799 | 65536 |
| 44 | 400 | 456828 | 65536 | 400 | 153995 | 65536 |
| 49.5 | 400 | 423351 | 65536 | 400 | 151779 | 65536 |
| 51.5 | 400 | 382437 | 65536 | 400 | 163371 | 65536 |
| 68 | 400 | 347336 | 65536 | 400 | 86843 | 65536 |
| 71 | 400 | 324936 | 65536 | 400 | 91124 | 65536 |
| 74.5 | 400 | 303506 | 65536 | 400 | 90446 | 65536 |
| 92.5 | 400 | 261946 | 65536 | 400 | 67793 | 65536 |
| 96 | 400 | 228015 | 65536 | 400 | 66742 | 65536 |
| 99 | 400 | 200770 | 65536 | 400 | 68936 | 65536 |
| | | | | | | |

# COLONIC TRANSIT STUDY

DATASHEET 2 (COLON2)

**PATIENT:** Subject 14

**FOLDER:**

| TIME | ASCENDING COLON | | | | HEPATIC FLEXURE | | | |
|---|---|---|---|---|---|---|---|---|
| (Hours) | ANT | AREA | POST | AREA | ANT | AREA | POST | AREA |
| 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 20 | 194488 | 3932 | 44629 | 6562 | 134179 | 1618 | 40751 | 4440 |
| 23.5 | 159791 | 4792 | 34444 | 6562 | 126114 | 1618 | 33393 | 4440 |
| 27 | 72402 | 4792 | 19909 | 6562 | 36684 | 1618 | 11751 | 4440 |
| 44 | 3645 | 3504 | 1601 | 3825 | 5339 | 1618 | 1085 | 4440 |
| 49.5 | 3566 | 3504 | 2070 | 3107 | 3246 | 1618 | 1417 | 4440 |
| 51.5 | 3336 | 3504 | 2383 | 3107 | 3026 | 1618 | 1871 | 4440 |
| 68 | 4424 | 3504 | 1877 | 3107 | 721 | 1618 | 1591 | 4440 |
| 71 | 4343 | 3504 | 1842 | 3107 | 737 | 1618 | 1456 | 4440 |
| 74.5 | 1780 | 3504 | 1454 | 3107 | 512 | 1618 | 1057 | 4440 |
| 92.5 | 1701 | 3504 | 1698 | 3107 | 542 | 1618 | 1223 | 4440 |
| 96 | 1805 | 3504 | 1519 | 3107 | 515 | 1618 | 904 | 4440 |
| 99 | 1566 | 3504 | 1339 | 3107 | 1119 | 1618 | 919 | 4440 |
| | | | | | | | | |
| | | | | | | | | |
| | | | | | | | | |

| TIME (Hours) | | TRANSVERSE COLON | | | SPLENIC FLEXURE | | | |
|---|---|---|---|---|---|---|---|---|
| | ANT | AREA | POST | AREA | ANT | AREA | POST | AREA |
| 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 20 | 195422 | 4436 | 23824 | 4748 | 67278 | 1602 | 22194 | 3054 |
| 23.5 | 232403 | 4848 | 22553 | 4748 | 57903 | 2453 | 30447 | 3054 |
| 27 | 207644 | 4848 | 28518 | 5469 | 127060 | 2453 | 53084 | 3054 |
| 44 | 53718 | 4848 | 8789 | 5469 | 28585 | 2453 | 12073 | 3054 |
| 49.5 | 50133 | 4848 | 8701 | 5095 | 34263 | 2453 | 14285 | 3054 |
| 51.5 | 53346 | 4848 | 10576 | 5095 | 44122 | 2453 | 29101 | 3054 |
| 68 | 5710 | 4848 | 2813 | 5095 | 6661 | 2453 | 2912 | 3054 |
| 71 | 6704 | 4848 | 3069 | 5095 | 7545 | 2453 | 3057 | 3054 |
| 74.5 | 7876 | 4848 | 3468 | 5095 | 9376 | 2453 | 4413 | 3054 |
| 92.5 | 3637 | 3855 | 3482 | 5095 | 1967 | 2453 | 2172 | 3054 |
| 96 | 3193 | 3855 | 2585 | 5095 | 3454 | 2453 | 1895 | 3054 |
| 99 | 2528 | 3855 | 2264 | 5095 | 4798 | 2453 | 2677 | 3054 |
| | | | | | | | | |
| | | | | | | | | |
| | | | | | | | | |
| | | | | | | | | |

| DESCENDING COLON | | | | | | RECTO / SIGMOID | | |
|---|---|---|---|---|---|---|---|---|
| TIME(H) | ANT | AREA | POST | AREA | ANT | AREA | POST | AREA |
| 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 20 | 73219 | 5969 | 50860 | 5260 | 0 | 0 | 0 | 0 |
| 23.5 | 62416 | 5969 | 44695 | 7361 | 4175 | 2036 | 1645 | 1777 |
| 27 | 121038 | 6501 | 82231 | 7361 | 5425 | 2036 | 1483 | 1874 |
| 44 | 202843 | 6501 | 78869 | 6922 | 141400 | 6664 | 34237 | 7390 |
| 49.5 | 165432 | 6501 | 82169 | 6922 | 147207 | 6664 | 30219 | 7390 |
| 51.5 | 130408 | 6501 | 76192 | 6922 | 125810 | 6664 | 30672 | 7390 |
| 68 | 99052 | 6501 | 21614 | 6922 | 223933 | 6664 | 50270 | 7390 |
| 71 | 66415 | 6906 | 30204 | 6922 | 232782 | 8092 | 44440 | 7896 |
| 74.5 | 103794 | 6906 | 36296 | 6922 | 170318 | 8092 | 37867 | 7896 |
| 92.5 | 37079 | 6906 | 14182 | 6922 | 208253 | 8092 | 40836 | 7896 |
| 96 | 34103 | 6906 | 13886 | 6922 | 178500 | 8092 | 40371 | 7896 |
| 99 | 49388 | 6906 | 17936 | 6922 | 132874 | 8092 | 39844 | 7896 |
| | | | | | | | | |
| | | | | | | | | |
| | | | | | | | | |

# COLONIC TRANSIT STUDY - CALCULATIONS

**Patient:** **Subject 14**

**Folder No:**

| TIME OF IMAGING (Hours) | ACQ DURATION | COUNTS ANT | ACQ DURATION | COUNTS POST | REF. ACQ DURATION | ACQ DURATION CORR ANT | ACQ DURATION CORR POST |
|---|---|---|---|---|---|---|---|
| 3 | 141 | 314873 | 400 | 204662 | 400 | 893257 | 204662 |
| 20 | 400 | 741009 | 400 | 203409 | 400 | 741009 | 203409 |
| 23.5 | 386 | 693209 | 400 | 186304 | 400 | 718351 | 186304 |
| 27 | 400 | 607264 | 400 | 217799 | 400 | 607264 | 217799 |
| 44 | 400 | 456828 | 400 | 153995 | 400 | 456828 | 153995 |
| 49.5 | 400 | 423351 | 400 | 151779 | 400 | 423351 | 151779 |
| 51.5 | 400 | 382437 | 400 | 163371 | 400 | 382437 | 163371 |
| 68 | 400 | 347336 | 400 | 86843 | 400 | 347336 | 86843 |
| 71 | 400 | 324936 | 400 | 91124 | 400 | 324936 | 91124 |
| 74.5 | 400 | 303506 | 400 | 90446 | 400 | 303506 | 90446 |
| 92.5 | 400 | 261946 | 400 | 67793 | 400 | 261946 | 67793 |
| 96 | 400 | 228015 | 400 | 66742 | 400 | 228015 | 66742 |
| 99 | 400 | 200770 | 400 | 68936 | 400 | 200770 | 68936 |
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |

| DECAY CORR ANT | DECAY CORR POST | GEO MEAN | % EXCRETED | COUNTS LOST |
|---|---|---|---|---|
| 921222 | 211069 | 440956 | 0 | 0 |
| 910077 | 249819 | 476817 | -8 | -35861 |
| 914557 | 237190 | 465751 | -6 | -24795 |
| 801440 | 287441 | 479966 | -9 | -39010 |
| 717980 | 242028 | 416859 | 5 | 24096 |
| 704053 | 252416 | 421562 | 4 | 19394 |
| 649217 | 277335 | 424324 | 4 | 16632 |
| 698578 | 174663 | 349307 | 21 | 91648 |
| 673987 | 189011 | 356918 | 19 | 84037 |
| 652590 | 194474 | 356247 | 19 | 84709 |
| 677663 | 175383 | 344747 | 22 | 96209 |
| 611484 | 178987 | 330828 | 25 | 110127 |
| 555275 | 190658 | 325373 | 26 | 115582 |
| | | | | |
| | | | | |
| | | | | |

| TIME OF IMAGING (Hours) | ASCENDING COLON ANT | POST | ANT DURATION & DECAY CORR | POST DURATION & DECAY CORR | GEO MEAN | % TOTAL INITIAL COUNTS |
|---|---|---|---|---|---|---|
| 3 | 0 | 0 | 0 | 0 | 0 | 0.00 |
| 20 | 194488 | 44629 | 238862 | 54811 | 114422 | 25.95 |
| 23.5 | 159791 | 34444 | 210814 | 43852 | 96149 | 21.80 |
| 27 | 72402 | 19909 | 95553 | 26275 | 50106 | 11.36 |
| 44 | 3645 | 1601 | 5729 | 2516 | 3797 | 0.86 |
| 49.5 | 3566 | 2070 | 5930 | 3443 | 4518 | 1.02 |
| 51.5 | 3336 | 2383 | 5663 | 4045 | 4786 | 1.09 |
| 68 | 4424 | 1877 | 8898 | 3775 | 5796 | 1.31 |
| 71 | 4343 | 1842 | 9008 | 3821 | 5867 | 1.33 |
| 74.5 | 1780 | 1454 | 3827 | 3126 | 3459 | 0.78 |
| 92.5 | 1701 | 1698 | 4401 | 4393 | 4397 | 1.00 |
| 96 | 1805 | 1519 | 4841 | 4074 | 4441 | 1.01 |
| 99 | 1566 | 1339 | 4331 | 3703 | 4005 | 0.91 |

| TIME OF IMAGING (Hours) | HEPATIC FLEXURE ANT | POST | ANT DURATION & DECAY CORR | POST DURATION & DECAY CORR | GEO MEAN | % TOTAL INITIAL COUNTS |
|---|---|---|---|---|---|---|
| 3 | 0 | 0 | 0 | 0 | 0 | 0.00 |
| 20 | 134179 | 40751 | 164793 | 50049 | 90817 | 20.60 |
| 23.5 | 126114 | 33393 | 166383 | 42514 | 84105 | 19.07 |
| 27 | 36684 | 11751 | 48414 | 15508 | 27401 | 6.21 |
| 44 | 5339 | 1085 | 8391 | 1705 | 3783 | 0.86 |
| 49.5 | 3246 | 1417 | 5398 | 2357 | 3567 | 0.81 |
| 51.5 | 3026 | 1871 | 5137 | 3176 | 4039 | 0.92 |
| 68 | 721 | 1591 | 1450 | 3200 | 2154 | 0.49 |
| 71 | 737 | 1456 | 1529 | 3020 | 2149 | 0.49 |
| 74.5 | 512 | 1057 | 1101 | 2273 | 1582 | 0.36 |
| 92.5 | 542 | 1223 | 1402 | 3164 | 2106 | 0.48 |
| 96 | 515 | 904 | 1381 | 2424 | 1830 | 0.41 |
| 99 | 1119 | 919 | 3095 | 2542 | 2805 | 0.64 |

| TIME OF IMAGING (Hours) | TRANSVERSE COLON ANT | POST | ANT DURATION & DECAY CORR | POST DURATION & DECAY CORR | GEO MEAN | % TOTAL INITIAL COUNTS |
|---|---|---|---|---|---|---|
| 3 | | | 0 | 0 | 0 | 0.00 |
| 20 | 195422 | 23824 | 240009 | 29260 | 83801 | 19.00 |
| 23.5 | 232403 | 22553 | 306611 | 28713 | 93828 | 21.28 |
| 27 | 207644 | 28578 | 274039 | 37716 | 101664 | 23.06 |
| 44 | 53718 | 8789 | 84427 | 13813 | 34150 | 7.74 |
| 49.5 | 50133 | 8701 | 83374 | 14470 | 34734 | 7.88 |
| 51.5 | 53346 | 10576 | 90559 | 17954 | 40322 | 9.14 |
| 68 | 5710 | 2813 | 11484 | 5658 | 8061 | 1.83 |
| 71 | 6704 | 3069 | 13906 | 6366 | 9408 | 2.13 |
| 74.5 | 7876 | 3468 | 16935 | 7457 | 11237 | 2.55 |
| 92.5 | 3637 | 3482 | 9409 | 9008 | 9206 | 2.09 |
| 96 | 3193 | 2585 | 8563 | 6932 | 7705 | 1.75 |
| 99 | 2528 | 2264 | 6992 | 6262 | 6617 | 1.50 |

| TIME OF IMAGING (Hours) | SPLENIC FLEXURE ANT | POST | ANT DURATION & DECAY CORR | POST DURATION & DECAY CORR | GEO MEAN | % TOTAL INITIAL COUNTS |
|---|---|---|---|---|---|---|
| 3 | | | 0 | 0 | 0 | 0.00 |
| 20 | 67278 | 22194 | 82628 | 27258 | 47458 | 10.76 |
| 23.5 | 57903 | 30447 | 76392 | 38763 | 54417 | 12.34 |
| 27 | 127060 | 53084 | 167688 | 70058 | 108388 | 24.58 |
| 44 | 28585 | 12073 | 44926 | 18975 | 29197 | 6.62 |
| 49.5 | 34263 | 14285 | 56981 | 23757 | 36792 | 8.34 |
| 51.5 | 44122 | 29101 | 74901 | 49401 | 60829 | 13.79 |
| 68 | 6661 | 2912 | 13397 | 5857 | 8858 | 2.01 |
| 71 | 7545 | 3057 | 15650 | 6341 | 9962 | 2.26 |
| 74.5 | 9376 | 4413 | 20160 | 9489 | 13831 | 3.14 |
| 92.5 | 1967 | 2172 | 5089 | 5619 | 5347 | 1.21 |
| 96 | 3454 | 1895 | 9263 | 5082 | 6861 | 1.56 |
| 99 | 4798 | 2677 | 13270 | 7404 | 9912 | 2.25 |

| TIME OF IMAGING (Hours) | DESCENDING COLON ANT | POST | ANT DURATION & DECAY CORR | POST DURATION & DECAY CORR | GEO MEAN | % TOTAL INITIAL COUNTS |
|---|---|---|---|---|---|---|
| 3 | | | 0 | 0 | 0 | 0.00 |
| 20 | 73219 | 50860 | 89925 | 62464 | 74947 | 17.00 |
| 23.5 | 62416 | 44695 | 82346 | 56903 | 68452 | 15.52 |
| 27 | 121038 | 82231 | 159741 | 108525 | 131666 | 29.86 |
| 44 | 202843 | 78869 | 318801 | 123956 | 198789 | 45.08 |
| 49.5 | 165432 | 82169 | 275121 | 136651 | 193896 | 43.97 |
| 51.5 | 130408 | 76192 | 221378 | 129342 | 169214 | 38.37 |
| 68 | 99052 | 21614 | 199218 | 43471 | 93060 | 21.10 |
| 71 | 66415 | 30204 | 137759 | 62650 | 92901 | 21.07 |
| 74.5 | 103794 | 36296 | 223175 | 78043 | 131974 | 29.93 |
| 92.5 | 37079 | 14182 | 95925 | 36689 | 59325 | 13.45 |
| 96 | 34103 | 13886 | 91456 | 37239 | 58359 | 13.23 |
| 99 | 49388 | 17936 | 136594 | 49606 | 82316 | 18.67 |

| TIME OF IMAGING (Hours) | RECTO/SIGMOID ANT | POST | ANT DURATION & DECAY CORR | POST DURATION & DECAY CORR | GEO MEAN | % TOTAL INITIAL COUNTS |
|---|---|---|---|---|---|---|
| 3 | | | 0 | 0 | 0 | 0.00 |
| 20 | | | 0 | 0 | 0 | 0.00 |
| 23.5 | 4175 | 1645 | 5508 | 2094 | 3396 | 0.77 |
| 27 | 5425 | 1483 | 7160 | 1957 | 3743 | 0.85 |
| 44 | 141400 | 34237 | 222233 | 53809 | 109353 | 24.80 |
| 49.5 | 147207 | 30219 | 244812 | 50256 | 110920 | 25.15 |
| 51.5 | 125810 | 30672 | 213573 | 52068 | 105453 | 23.91 |
| 68 | 223933 | 50270 | 450384 | 101105 | 213392 | 48.39 |
| 71 | 232782 | 44440 | 482839 | 92178 | 210967 | 47.84 |
| 74.5 | 170318 | 37867 | 366213 | 81421 | 172677 | 39.16 |
| 92.5 | 208253 | 40836 | 538757 | 105644 | 238572 | 54.10 |
| 96 | 178500 | 40371 | 478696 | 108266 | 227654 | 51.63 |
| 99 | 132874 | 39844 | 367493 | 110198 | 201239 | 45.64 |

| TIME (H) | RSIDE % | LSIDE % | GC |
|---|---|---|---|
| 3 | 0.00 | 0.00 | 0.0 |
| 20 | 65.55 | 27.76 | 2.3 |
| 23.5 | 62.16 | 28.63 | 2.4 |
| 27 | 40.63 | 55.29 | 3.2 |
| 44 | 9.46 | 76.50 | 4.5 |
| 49.5 | 9.71 | 77.47 | 4.5 |
| 51.5 | 11.15 | 76.08 | 4.4 |
| 68 | 3.63 | 71.51 | 5.6 |
| 71 | 3.95 | 71.17 | 5.4 |
| 74.5 | 3.69 | 72.23 | 5.4 |
| 92.5 | 3.56 | 68.77 | 5.6 |
| 96 | 3.17 | 66.42 | 5.6 |
| 99 | 3.04 | 66.55 | 5.7 |

| TIME (H) | AC % | HF % | TC % | SF % | DC % | R/S % | TOTAL % |
|---|---|---|---|---|---|---|---|
| 3 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 20 | 25.95 | 20.60 | 19.00 | 10.76 | 17.00 | 0.00 | 93.31 |
| 23.5 | 21.80 | 19.07 | 21.28 | 12.34 | 15.52 | 0.77 | 90.79 |
| 27 | 11.36 | 6.21 | 23.06 | 24.58 | 29.86 | 0.85 | 95.92 |
| 44 | 0.86 | 0.86 | 7.74 | 6.62 | 45.08 | 24.80 | 85.97 |
| 49.5 | 1.02 | 0.81 | 7.88 | 8.34 | 43.97 | 25.15 | 87.18 |
| 51.5 | 1.09 | 0.92 | 9.14 | 13.79 | 38.37 | 23.91 | 87.23 |
| 68 | 1.31 | 0.49 | 1.83 | 2.01 | 21.10 | 48.39 | 75.14 |
| 71 | 1.33 | 0.49 | 2.13 | 2.26 | 21.07 | 47.84 | 75.12 |
| 74.5 | 0.78 | 0.36 | 2.55 | 3.14 | 29.93 | 39.16 | 75.92 |
| 92.5 | 1.00 | 0.48 | 2.09 | 1.21 | 13.45 | 54.10 | 72.33 |
| 96 | 1.01 | 0.41 | 1.75 | 1.56 | 13.23 | 51.63 | 69.59 |
| 99 | 0.91 | 0.64 | 1.50 | 2.25 | 18.67 | 45.64 | 69.60 |

# ANNEXURE B

## INTRODUCTION

A case history for each subject, analogue images, graph of the geometric centre, parametric images, and the graph showing arrival and clearance of the activity in the right and left sides of the colon, for each one, are presented here. The subjects are presented under the heading of their final categorisation, namely, intermediate transit, generalised delay, right-sided delay and left sided delay. The categorisation was made from the analogue images, geometric centre, parametric images and graph of the right and left sides of the colon. The anterior and posterior analogue images are displayed for the first subject of each category thereafter only the anterior images are displayed. The times laid down in the protocol are used during the description of the methods. The analogue images are however, labeled with the actual scanning time

# INTERMEDIATE TRANSIT

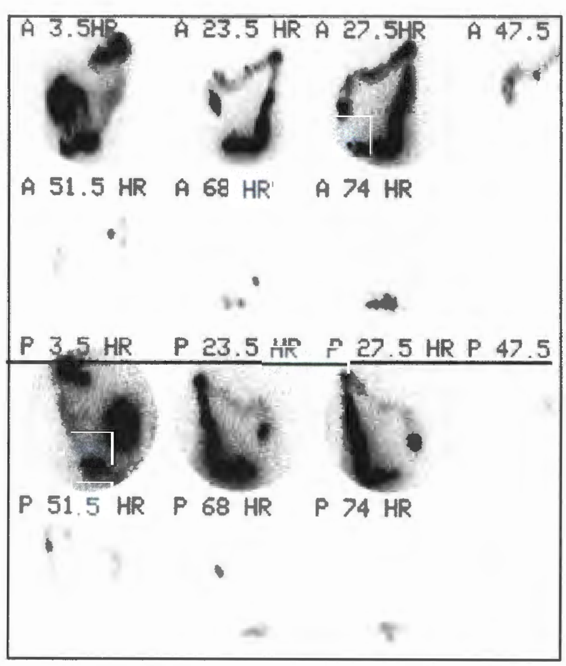
## SUBJECT 11

Subject number 11 was 27 years old at the time of the study. At the age of 17 years, he sustained a C4 spinal cord injury when a tree fell on the car in which he was traveling. He was motor and sensory incomplete with a C rating on the Frankel Scale. He lives at home and has a full time caregiver. He is mobile in a motorised wheel chair that he controls with his mouth.

On the analogue images (Figure 2), the activity was visible in the stomach and small bowel at 3.5 hours. At 24 hours the activity was spread from caecum to recto-sigmoid with the bulk of the activity (85%) lying in the left side of the colon. By 48 hours only 2.35% of the initial activity was left in the colon. At 75 hours the study was terminated because most of the activity had been excreted and only 2% was left in the recto-sigmoid.

### Analogue images

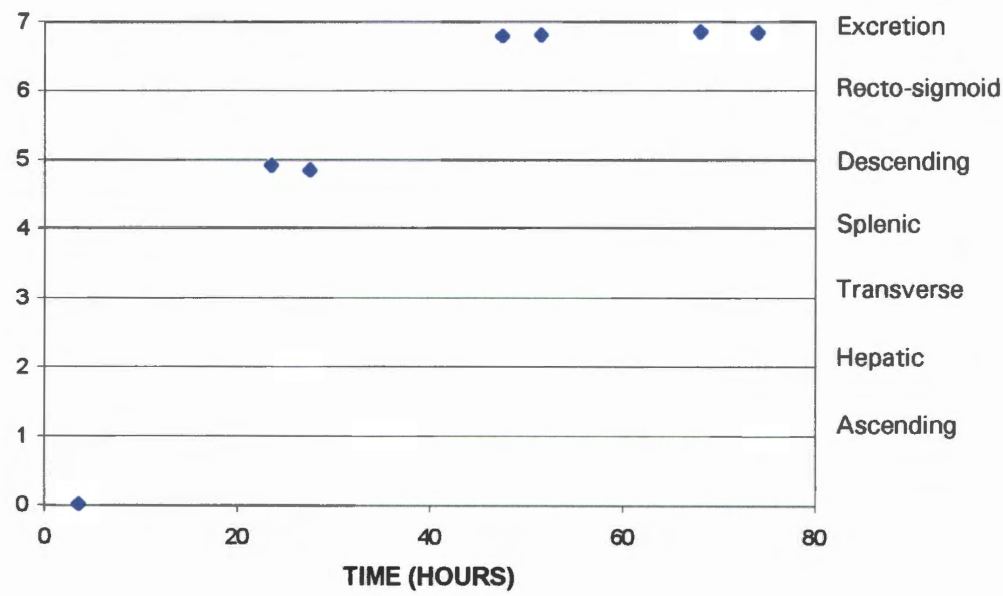
**FIGURE 2**



## Geometric centre

The geometric center (Graph 3) was situated proximal to the descending colon at 24 hours. From 48 hours until the end of the study the geometric centre was positioned between the recto-sigmoid and excretion.

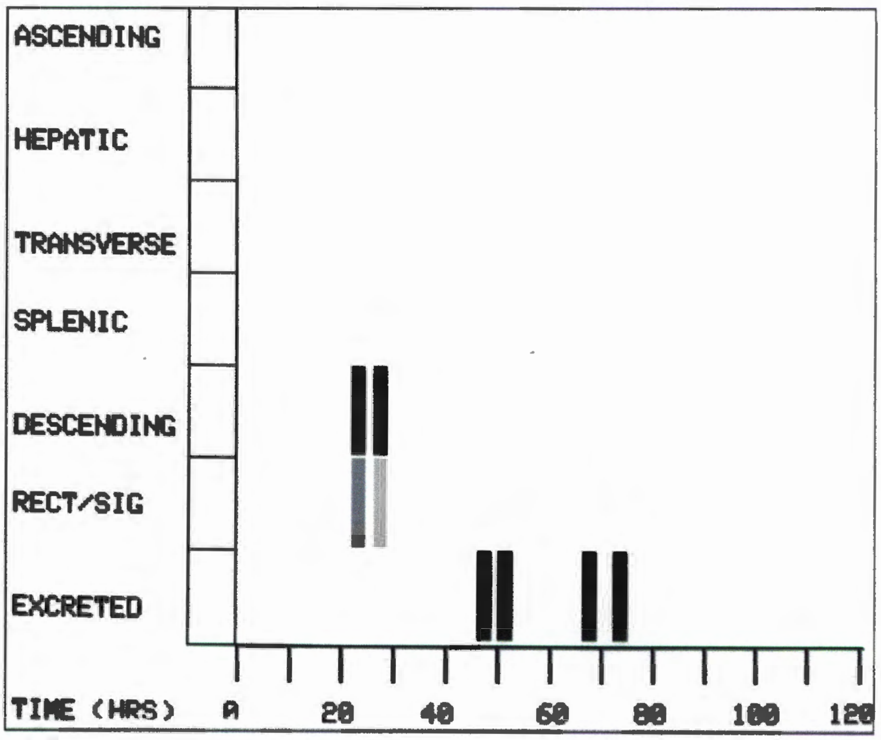
**GRAPH 3**



## Parametric images

The parametric images (Figure 3) showed activity in the descending colon and recto-sigmoid at 24 hours. By 48 hours excretion had taken place and the colon was empty.

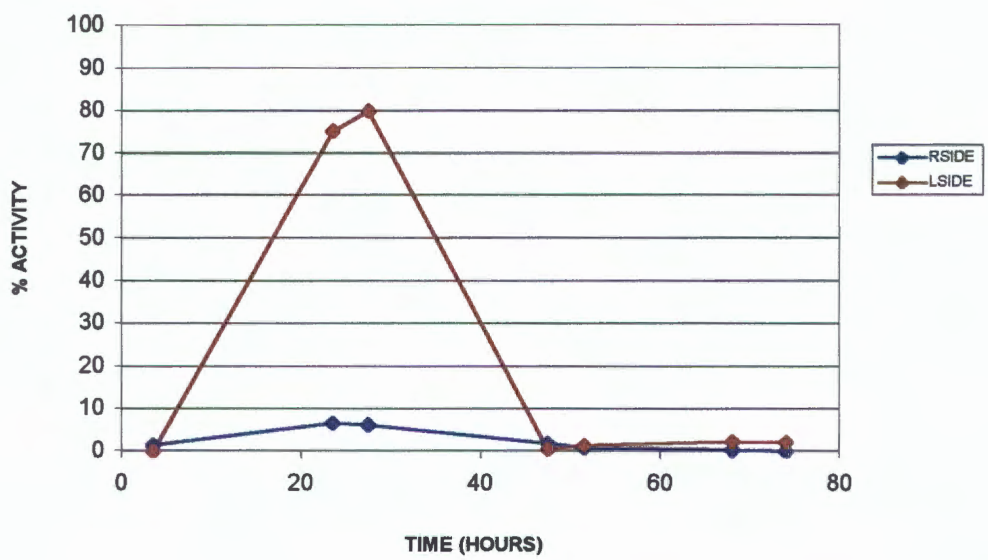
**FIGURE 3**



## Right and left sides of the colon

Graph 4 compared transit of the activity through the right side of the colon with that of the left side. It showed rapid transit of the activity through the right side with a corresponding rise in activity on the left side that reached a peak (80%) at 27 hours. The colon had emptied by 48 hours.

**GRAPH 4**




The analogue images, parametric images and the graph comparing right side and left side transit through the colon all indicated intermediate transit.

This subject was one of two subjects who did not use any artificial means of stimulating defaecation. He was also one of three patients who reported faecal excretion during the study.

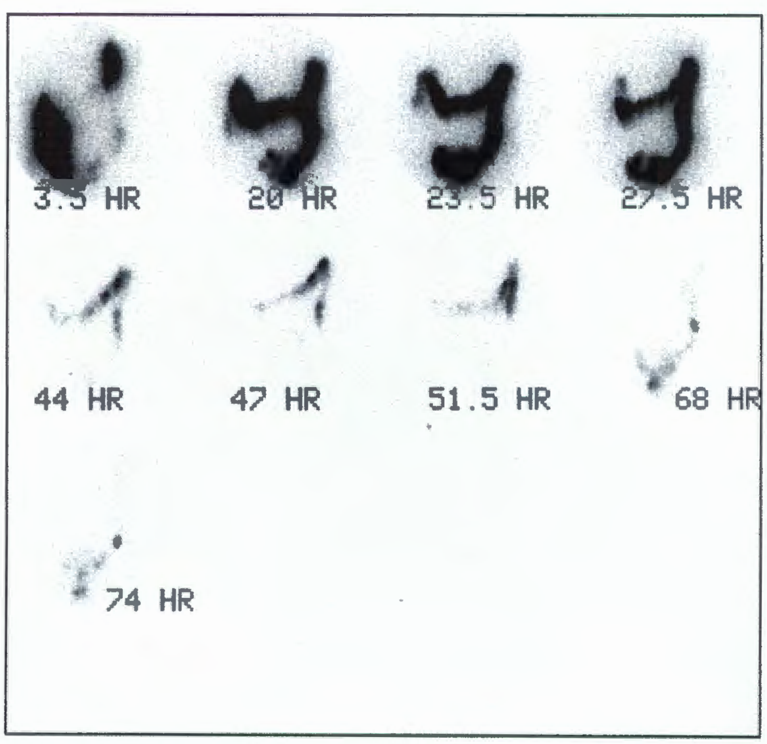
## SUBJECT 12

Subject number 12 was 29 years old at the time of the study. Seven years prior to the study he sustained C7 spinal cord injury when he dived into shallow water. He was motor complete, sensory incomplete and B on the Frankel Scale. He has partial use of his arms and is able to propel his own wheel chair. He lives at home and runs his own business.

### Analogue images

On the analogue images (Figure 4) subject 12 was the only subject to show activity within the ascending colon by 3 hours. The ascending colon was no longer visible at 24 hours and the activity was distributed from hepatic flexure to recto-sigmoid. By 48 hours only 6% of activity remained. The study was terminated at 74 hours with 5% of the activity remaining in the recto-sigmoid. Faecal evacuation took place before the 44 hour image.

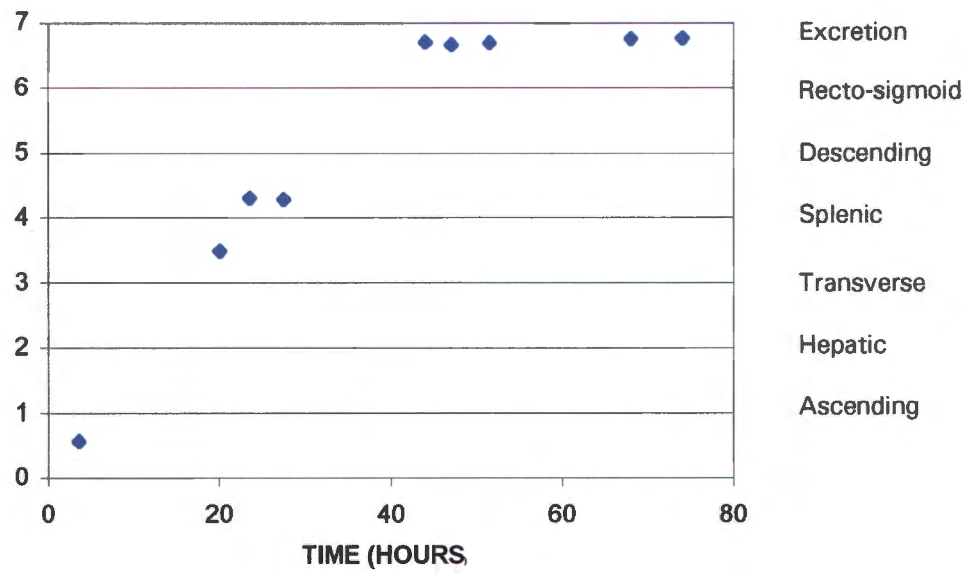
**FIGURE 4**



## Geometric centre

The geometric centre (Graph 5) was observed proximal to the ascending colon at 3 hours. At 24 hours the geometric centre was positioned midway between the transverse colon and splenic flexure. It had moved distal to the splenic flexure by 27 hours. By 48 hours, and until the end of the study, it was positioned between the rectosigmoid and excretion.

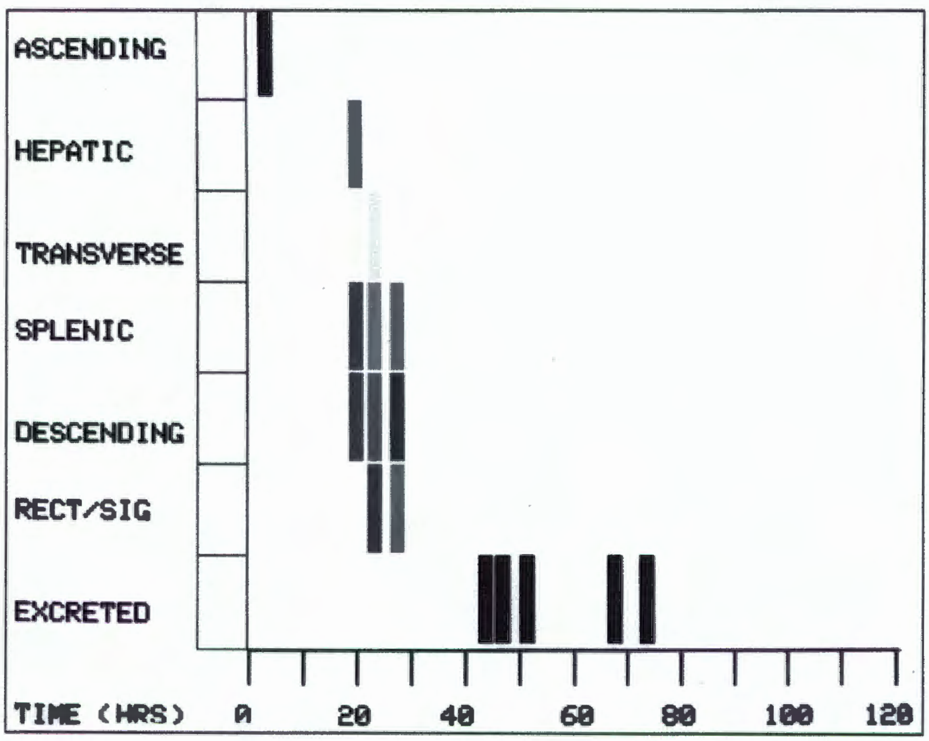
**GRAPH 5**



## Parametric images

The parametric images (Figure 5) showed activity in the ascending colon at 3 hours. At 24 hours the activity had cleared from the ascending colon and was distributed throughout the rest of the colon. Excretion was shown at 44 hours and the colon was empty.

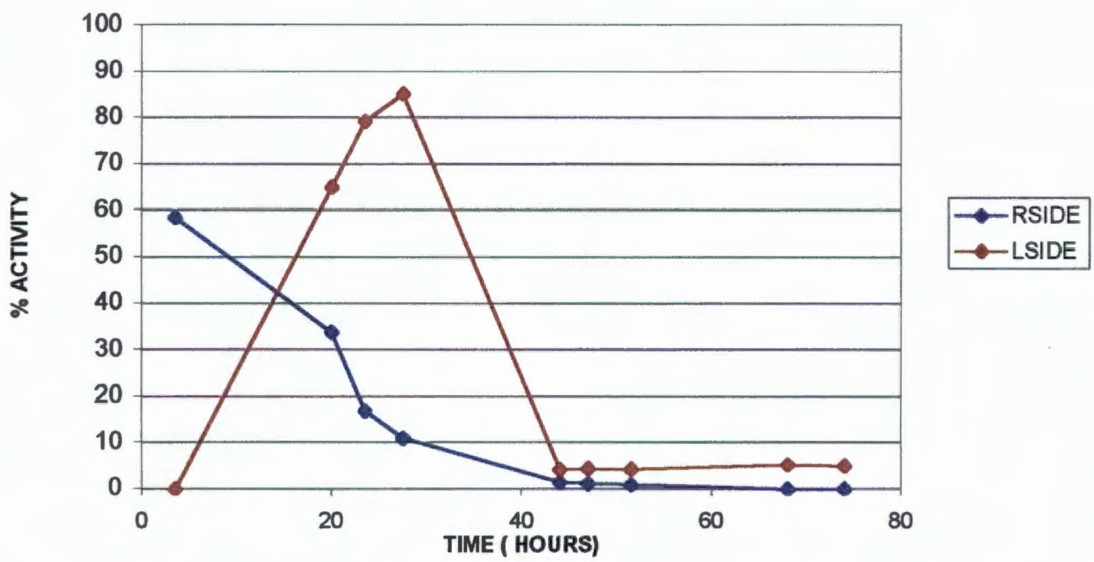
**FIGURE 5**



## Right and left sides of the colon

Graph 6 illustrates transit of the activity through the right and left side of the colon. Activity in the right colon dropped progressively over the first 48 hours of the study. Peak activity (59%) was seen in the left side at 27 hours, and was empty by 48 hours.

**GRAPH 6**




The analogue images, geometric centre, parametric images and the graph comparing the right side and left side transit through the colon all indicated intermediate transit.

This subject elected to have a colostomy because incontinence made it very difficult for him to work. The colostomy was sited in the sigmoid region. The colostomy has given him the freedom to travel overseas and to socialise. He is delighted with the results.

# GENERALISED DELAY

## SUBJECT 1

Subject 1 was 50 years old at the time of the study. Her spinal cord was injured at T3 by a stab wound, 13 years previously. She was motor and sensory complete from T7 with an A rating on the Frankel Scale. She lives at home with her family, who take care of her. She is mobile in a hand-driven wheelchair and fairly independent

### Analogue images

On the analogue images (Figures 6 & 7, anterior and posterior), the activity was visible in the stomach and small bowel at 3 hours. By 24 hours the activity had reached the splenic flexure and at 48 hours the activity was visible from ascending colon to descending colon with the bulk lying in the hepatic flexure (58%). At 74 hours the activity had cleared from the ascending colon and spread throughout the rest of the colon as far as the descending colon with the bulk appearing in the splenic flexure (46%). By 98 hours when the study was terminated activity was seen mainly in the left colon (45%).

**FIGURE 6**

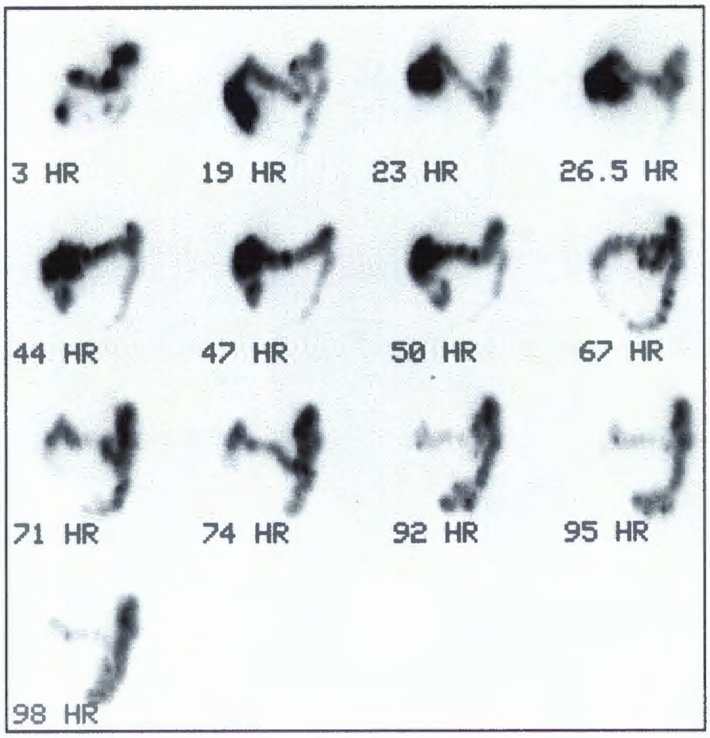
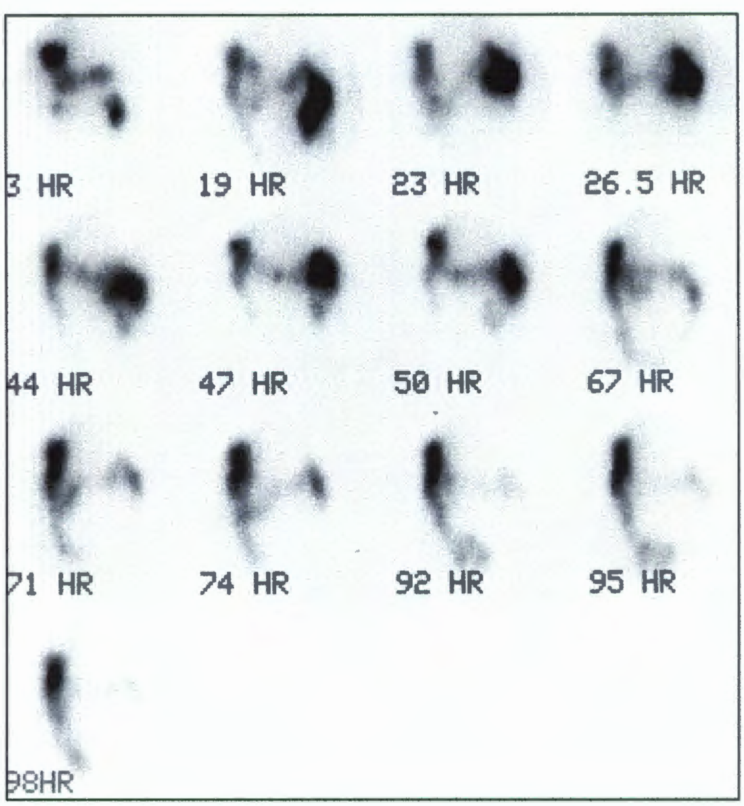


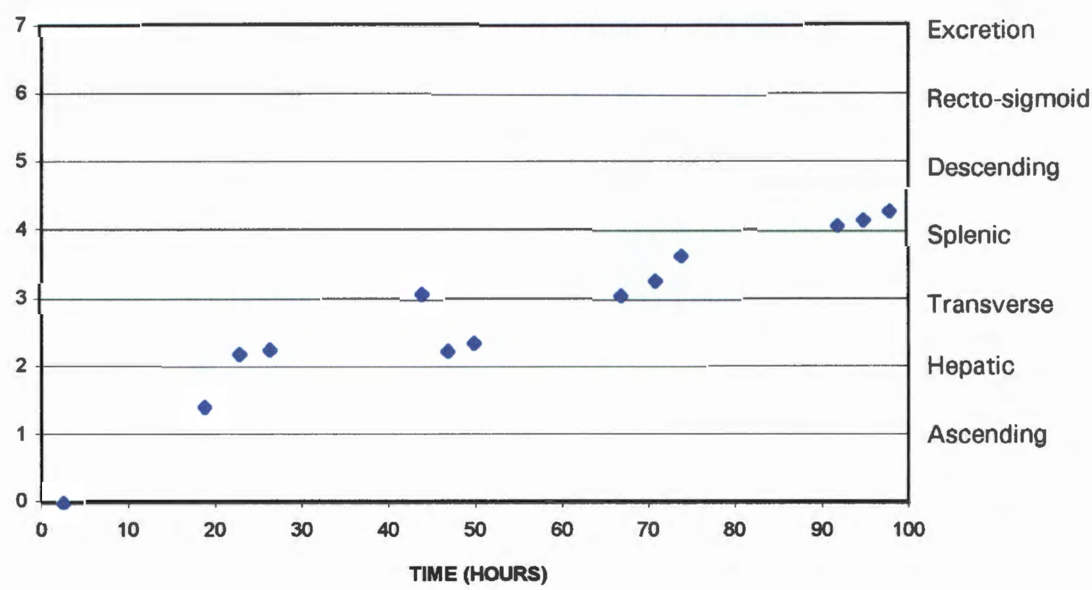

**FIGURE 7**



## Geometric centre

At 20 hours the geometric centre (Graph 7) was situated proximal to the hepatic flexure and by 24 hours had moved distal to the hepatic flexure. By 44 hours it was within the transverse colon but at 48 and 51 hours it had moved back towards the hepatic flexure. At 69 hours it was once again situated within the transverse colon and it moved steadily towards the splenic flexure over the next 7 hours. By 92 hours it was positioned within the splenic flexure and moved slowly towards the descending colon over the next 6 hours.

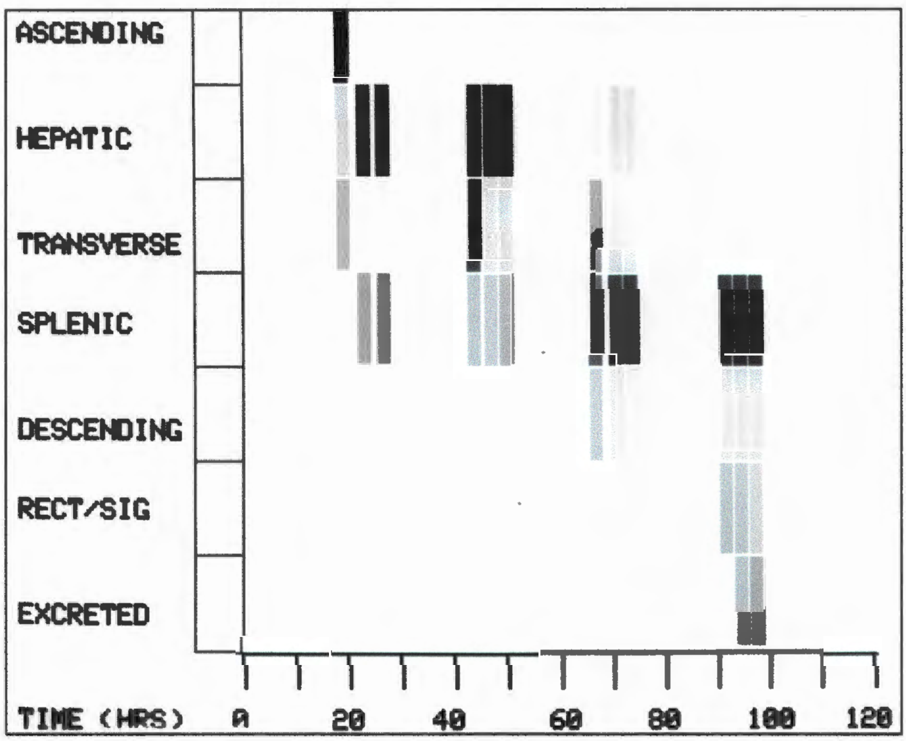
**GRAPH 7**



## Parametric images

On the parametric images (Figure 8) activity had reached the splenic flexure at 24 hours and only moved into the descending colon and recto-sigmoid by 92 hours. Minimal excretion was seen at 98 hours.

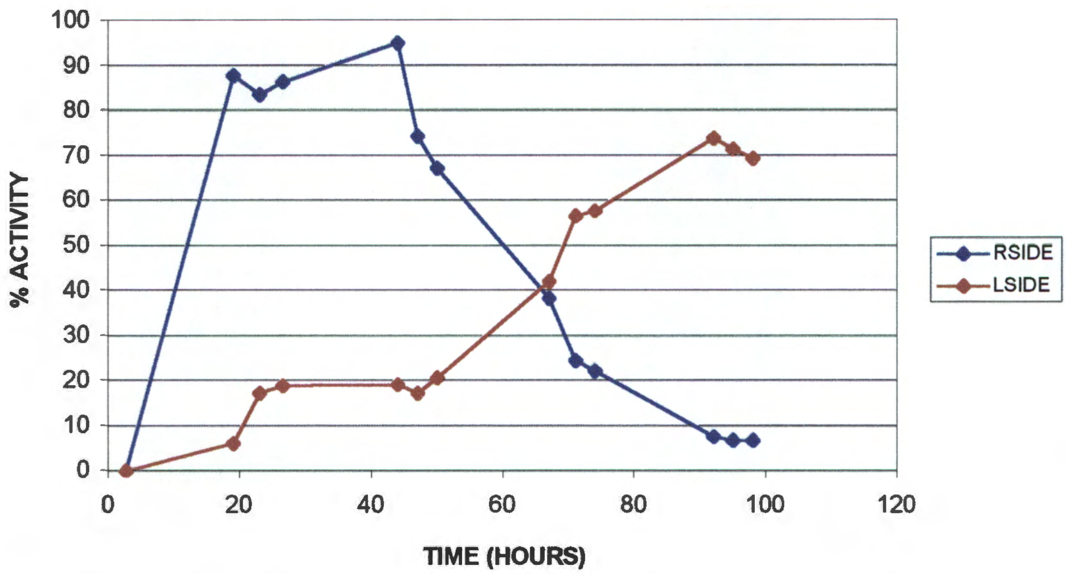
**FIGURE 8**



## Right and left sides of the colon

On Graph 8 illustrating transit of the activity through the right side of the colon with that of the left side, the activity on the right side had reached 88% by 20 hours. It reached a peak (92%) at 44 hrs and then dropped steadily. By 75 hours it had dropped to 23 %. The left side of the colon showed a steady increase in activity and by 75 hours it had reached 58%.

**GRAPH 8**




The analogue images, geometric center, parametric images and the graph comparing colonic transit through the right and left sides of the colon all indicated a colonic transit pattern of generalised delay

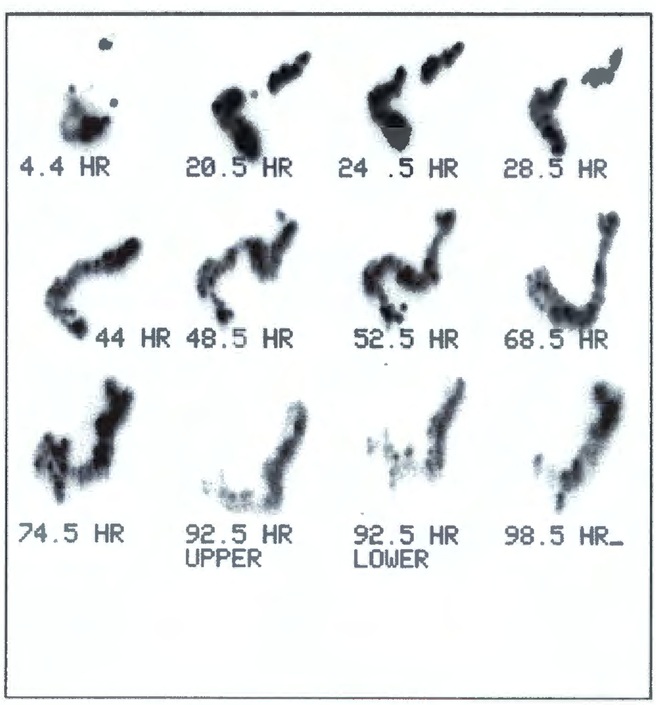
## SUBJECT 3

Subject 3 was 34 years old at the time of the study. She received her spinal cord injury in a MVA, 12 years previously. The spinal cord injury occurred at T5/6. C7 was also fractured but there was no cord damage at this level. She is motor and sensory complete and A on the Frankel Scale. She is married and runs her own business. She lives a very independent life style and has a hand-driven wheelchair.

### Analogue images

The bulk of the activity was seen in the small bowel on the 3 hour analogue images (Figure 9). By 24 hours activity was seen in the ascending colon, hepatic flexure, transverse colon and splenic flexure. By 48 hours the activity was spread throughout the colon as far as the splenic flexure. The ascending colon was no longer visible by 75 hours and activity appeared in the descending colon. By the end of the study, at 98 hours the bulk of the activity was in the descending colon (61%).

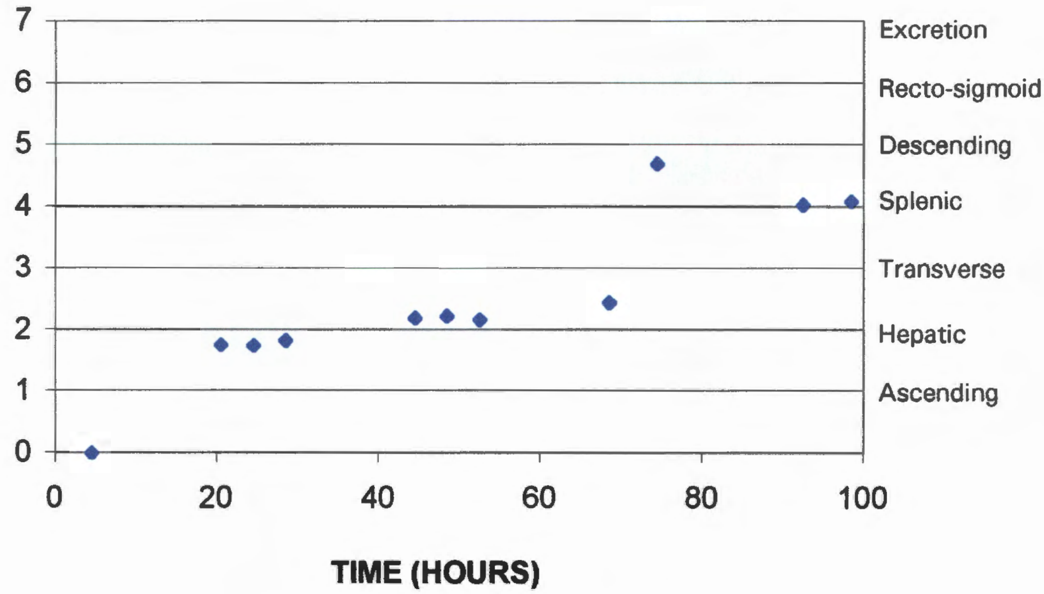
**FIGURE 9**



## Geometric centre

The geometric centre (Graph 9) lay proximal to the hepatic flexure at 20 hours. By 44 hours the geometric centre had moved distal to the transverse colon. By 69 hours it was situated proximal to the splenic flexure where it remained until 96 hours.

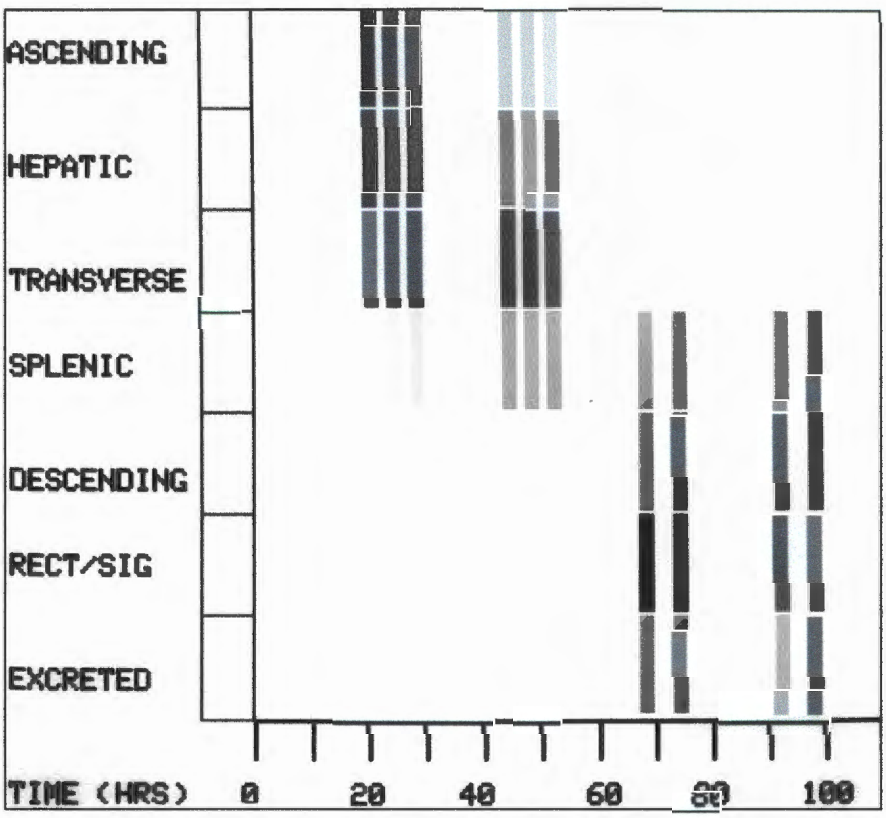
**GRAPH 9**



## Parametric images

The parametric images (Figure 10) showed activity in the ascending colon, hepatic flexure, and transverse colon by 24.5 hours. splenic flexure activity appeared by 44 hours. Excretion (14%) was shown at 68 hours.

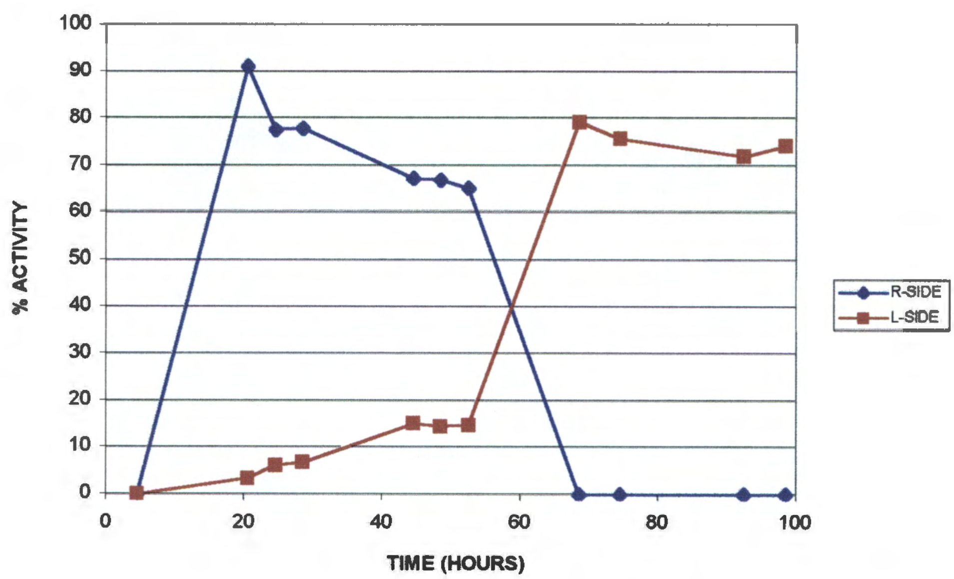
**FIGURE 10**



## Right and left sides of the colon

The graph of the arrival and clearance of the activity in the right and left sides of the colon (Graph 10) showed 85% of the activity in the right colon by 20 hours. By 69 hours the activity had dropped to 52% and by 75 hours 30%. The activity in the left colon rose slowly and at 69 hours there was 29% of the activity present. By 75 hours there was 45%.

**GRAPH 10**




This subject was absolutely adamant that no excretion had taken place during the study. She later complained that it had taken her weeks to re-establish her bowel regimen.

The pattern of colonic transit seen on the analogue images was that of right-sided delay. The parametric images showed generalized delay. Excretion took place as late as 68 hours and not within the 48 hours of intermediate transit. The graph of the right and left sides of the colon and the geometric centre were also indicative of generalized delay.

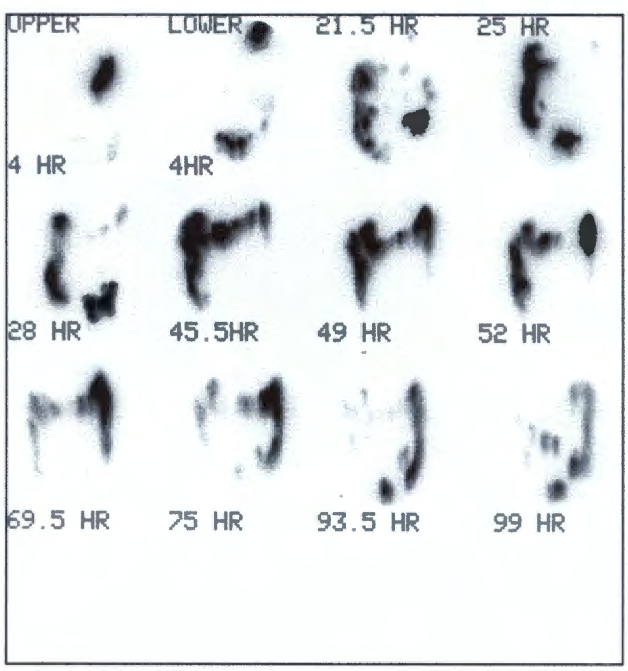
## SUBJECT 9

Subject 9 was 21 years old at the time of the study. He received his spinal cord injury 4 years previously in a MVA. His spinal cord was injured at C4. He is motor complete and sensory incomplete with a B rating on the Frankel scale. He lives at home where he has a care-giver during the day and is cared for by his parents at night and over the weekends. He is mobile in a motorized wheelchair, which he controls with his mouth.

### Analogue images

On the analogue images (Figure 11), the activity was seen in the stomach and small bowel at 3 hours. By 24 hours the ascending colon, hepatic flexure and proximal transverse colon were visible. By 48 hours the activity stretched from the ascending colon to the splenic flexure. At 75 hours activity could be seen in the recto-sigmoid and by 98 hours, when the study ended, activity was still visible throughout the colon and the recto-sigmoid (21%) was distended.

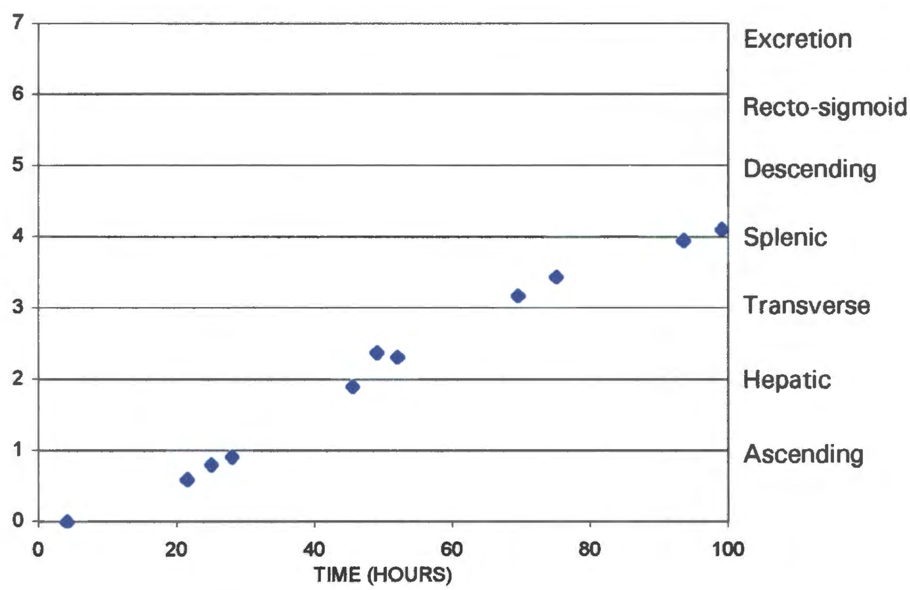
**FIGURE 11**



## Geometric centre

The geometric centre (Graph 11) was positioned proximal to the ascending colon at 20 hours where it remained for the next 6.5 hours. By 45.5 hours it had reached the hepatic flexure and by 52 hours it had moved distal to the splenic flexure. By 69 hours the geometric centre was situated proximal to the transverse colon. It had reached the splenic flexure by 92 hours where it remained until the end of the study at 98 hours.

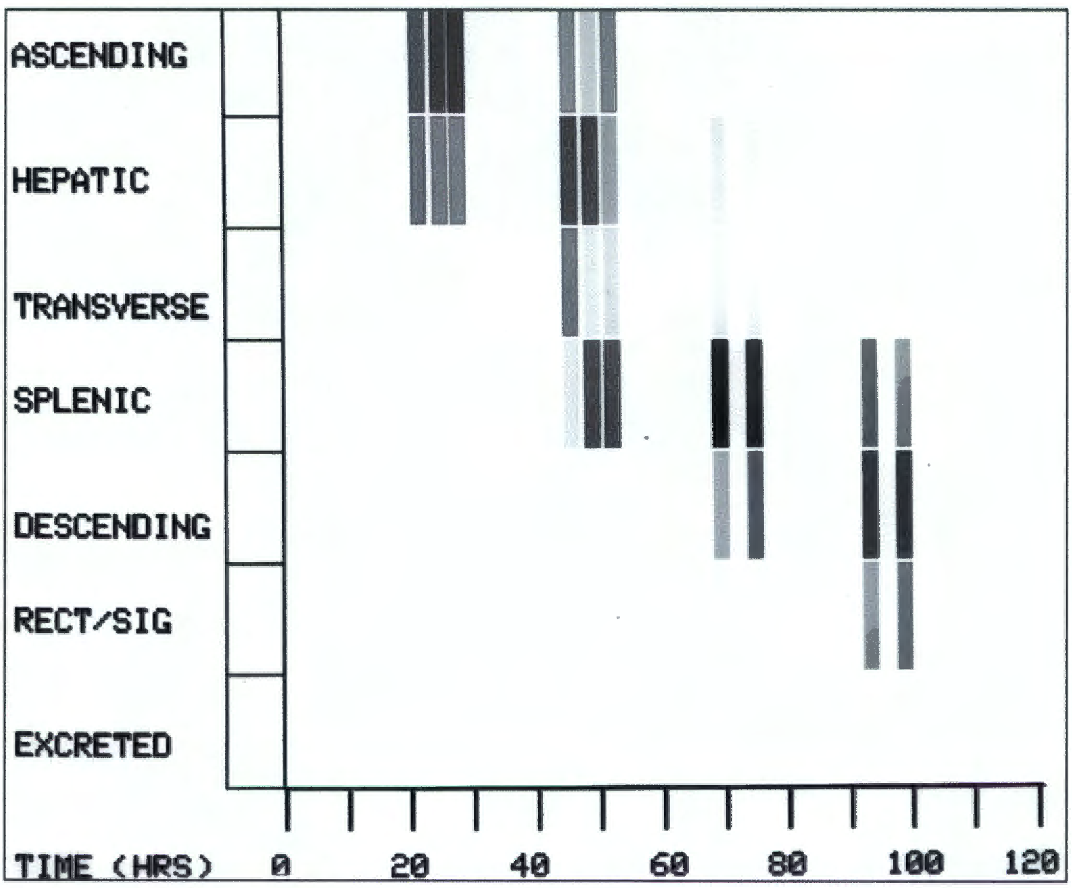
**GRAPH 11**



## Parametric images

The parametric images (Figure 12) showed a steady but delayed progression of activity through the colon. No excretion was visible

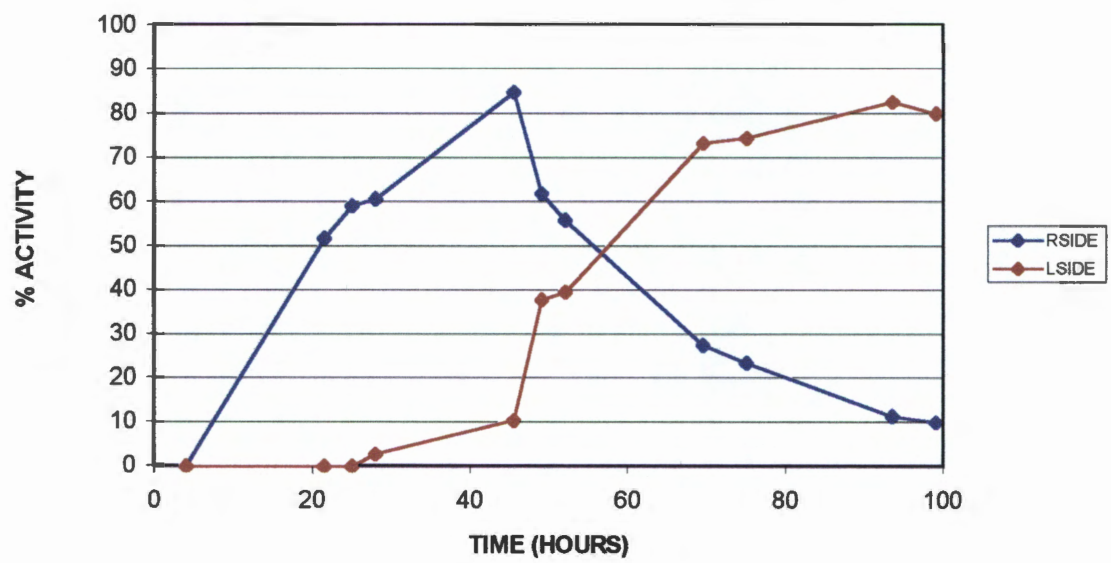
FIGURE 12



## Right and left sides of the colon

On the graph of the arrival and clearance of the activity in the right and left sides (Graph 12), the activity in the right side reached a peak (85%) at 44 hours. It then dropped steadily and at 72 hours had reached 28%. The activity in the left side rose steadily from 24 hours and by 69 hours it had reached 73%.

**GRAPH 12**




The analogue images showed a pattern of generalised delay as did the geometric center, parametric images and the graph of the right and left sides of the colon.

This subject elected to have a colostomy because his bowel management dominated his and his family's lives and he hated the loss of dignity that he suffered. A left muscle split with sigmoid loop was performed. Both he and his family are delighted with the colostomy.

# RIGHT-SIDED DELAY

## SUBJECT 2

Subject 2 was 39 years old at the time of the study. His spinal cord injury, at T9/10 was caused by a MVA and occurred 16 years previously. He is motor complete and sensory incomplete with a B rating on the Frankel Scale. He lives at home and helps to run the family farm. He is mobile in a hand-driven wheelchair.

### Analogue images

On the analogue images (Figure 13 & 14, anterior and posterior), the stomach and small bowel were visible at 3 hours. At 24 hours activity was seen in the ascending colon and as far as mid transverse colon. By 48 hours activity was visible in the small bowel, caecum and ascending colon and had traveled further along the transverse colon. At 75 hours the activity was spread from ascending colon to splenic flexure with the bulk of the activity lying in the transverse colon (30%). This picture remained unchanged at 98 hours.

**FIGURE 13**

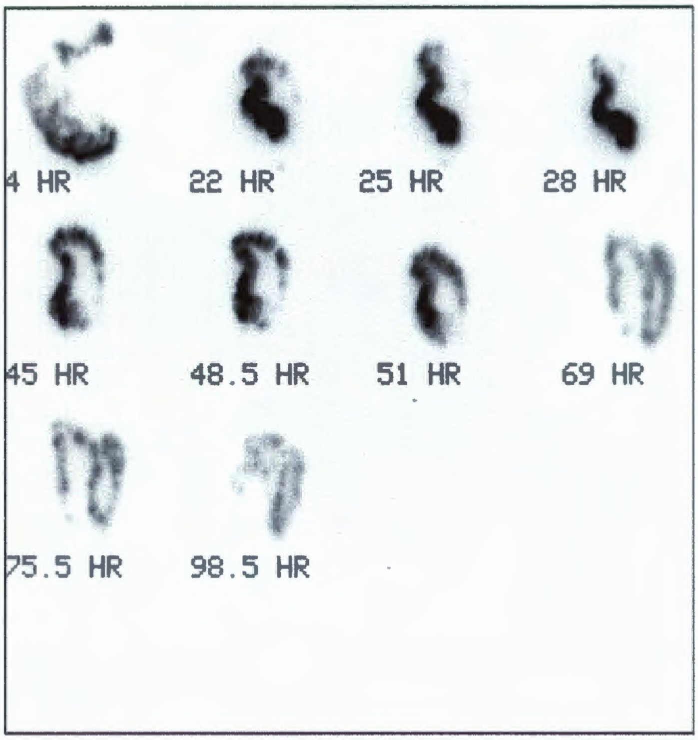
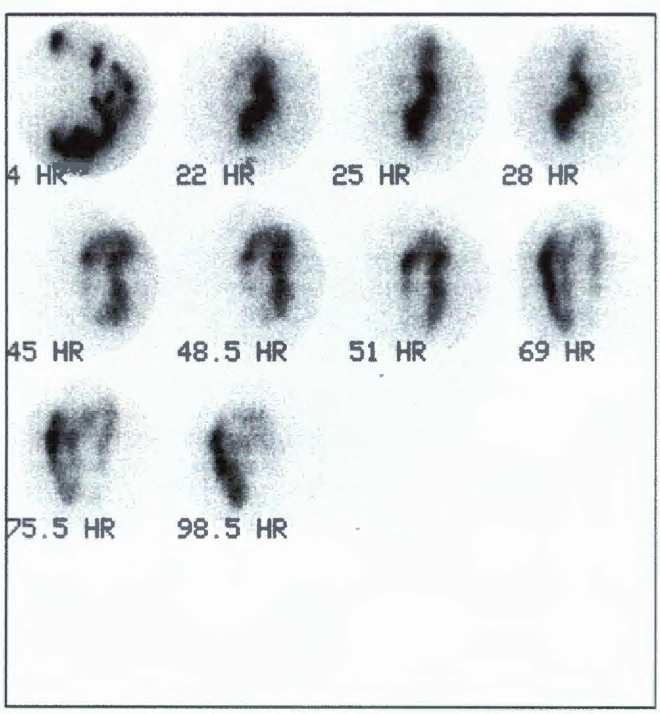


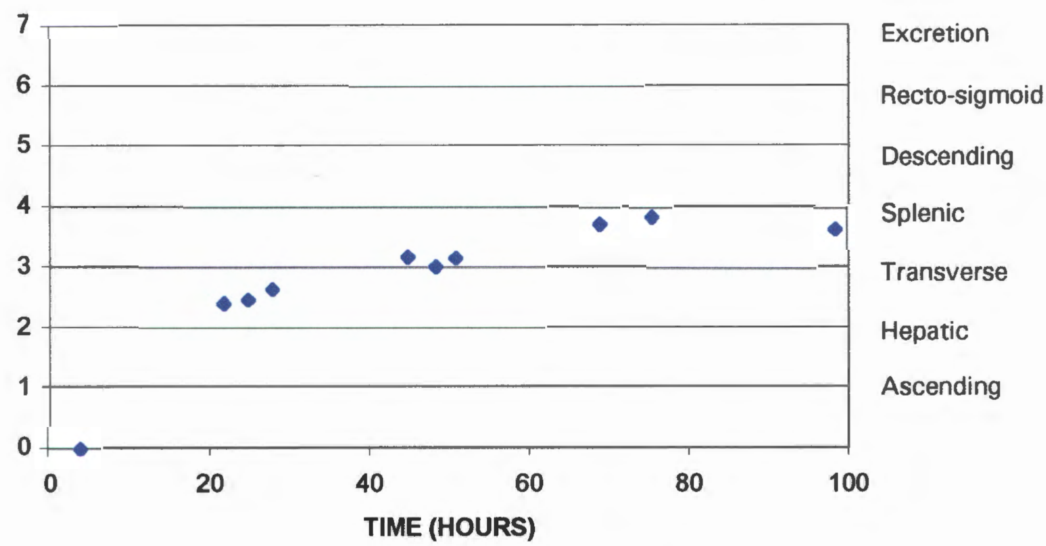

**FIGURE 14**



## Geometric centre

At 20 hours the geometric centre (Graph 13) was seen between the hepatic flexure and transverse colon and it continued to move along the transverse colon for the next 6 hours. By 44 hours it had moved distal to the transverse colon where it remained for the next 6 hours. It was positioned distal to the splenic flexure by 69 hours and remained there until the end of the study at 98 hours.

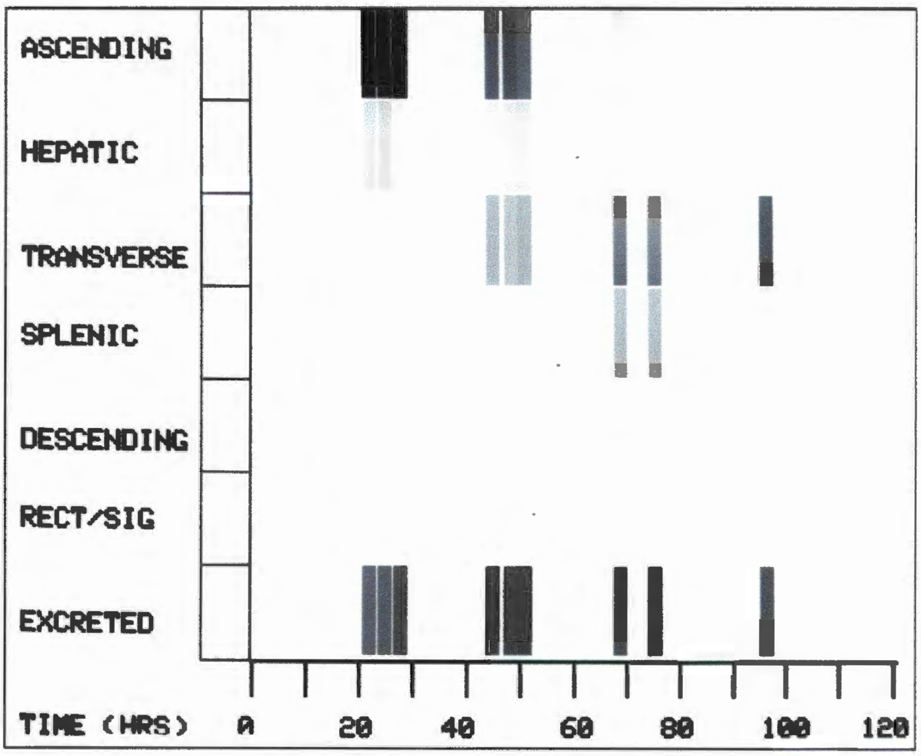
**GRAPH 13**



## Parametric images

This subject showed early excretion on the parametric images at 24 hours (23%) (Figure 15). However, activity was only seen in the transverse colon by 44 hours and only appeared in the splenic flexure by 69 hours.

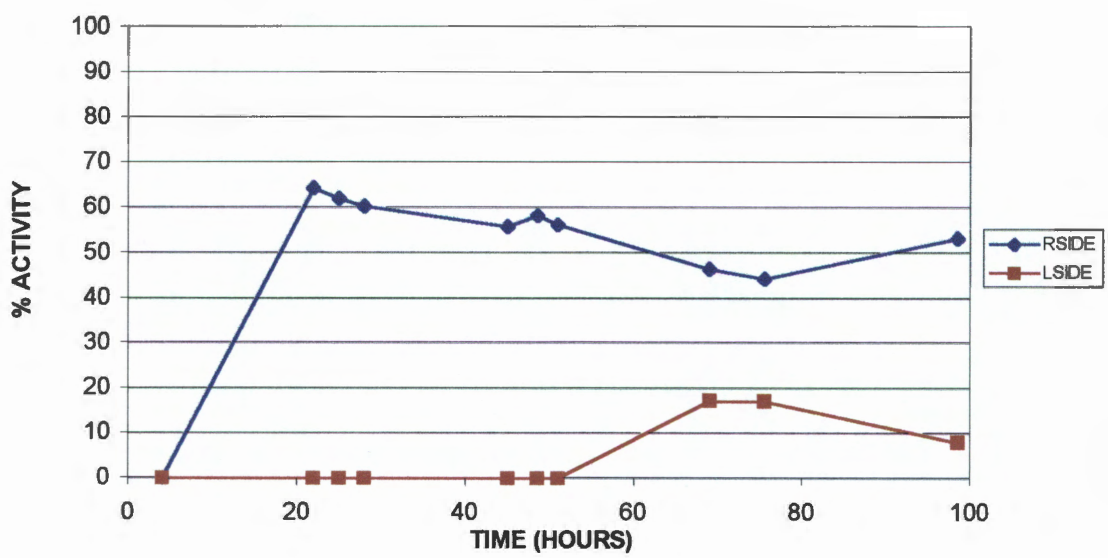
**FIGURE 15**



## Right and left sides of the colon

On the time-activity graph of the arrival and clearance of activity in the right and left sides of the colon (Graph 14) activity was seen in the right colon (65%) at 20 hours. By 75 hours there was 45% left in the right colon. Activity appeared in the left colon at 51 hours and by 75 hours it had reached 18%.

**GRAPH 14**




The pattern of colonic transit seen on the analogue images, geometric center, parametric images and the graph of the right and left sides of the colon was indicative of right-sided delay. The excretion seen on the parametric images never exceeded 30%.

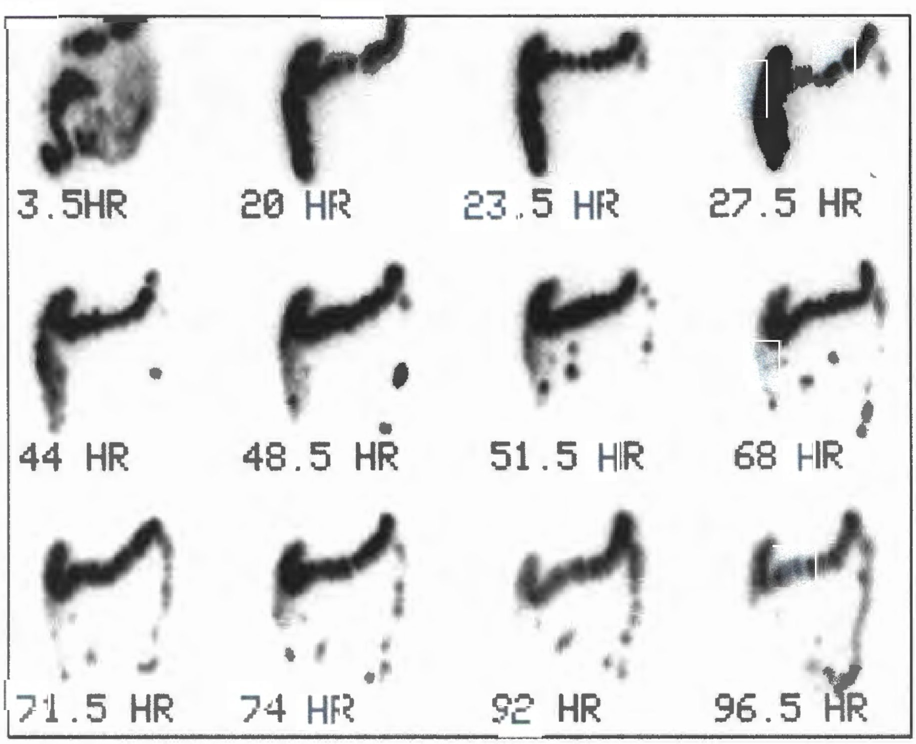
## SUBJECT 4

Subject was 45 years old at the time of the study. His spinal cord was injured at T12 during a MVA, 23 years previously. He is motor and sensory complete with an A rating on the Frankel Scale. He lives independently and takes care of himself. Initially he continued to work but incontinence forced him to stop.

### Analogue images

On the analogue images (Figure 16) activity was seen in the stomach and small bowel at 3 hours. At 24 hours activity was seen in the ascending colon, transverse colon and splenic flexure. By 48 hours the bulk of the activity was in the hepatic flexure (27%) and the transverse colon (24%). No change took place until 96 hours when activity appeared in the descending colon and recto-sigmoid.

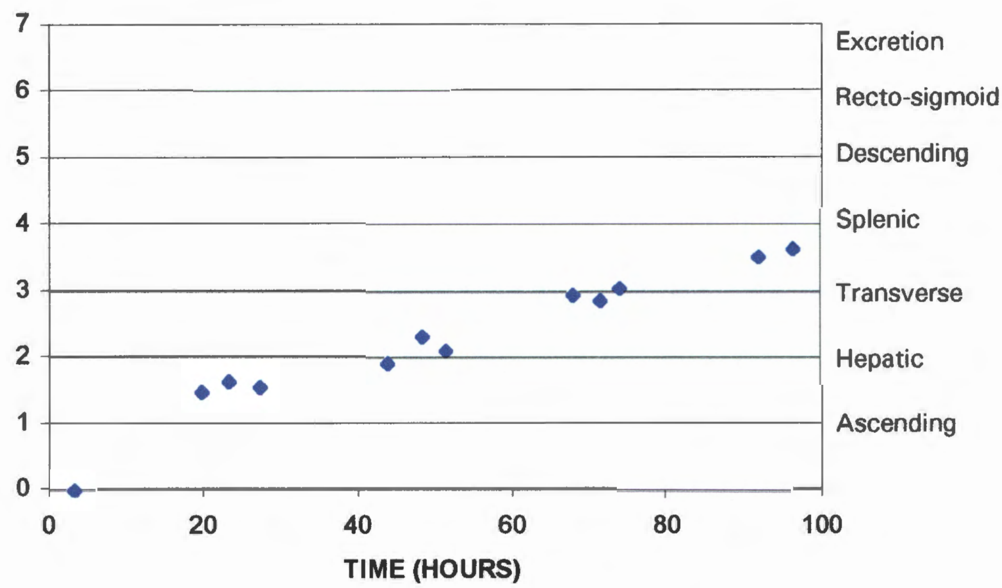
**FIGURE 16**



## Geometric centre

The geometric centre (Graph 15) lay proximal to the hepatic flexure between 20 and 27 hours. By 44 hours it lay within the hepatic flexure. By 51 hours it lay distal to the hepatic flexure. From 69 to 75 hours it lay within the transverse colon and by 96 hours the geometric centre was situated distal to the splenic flexure.

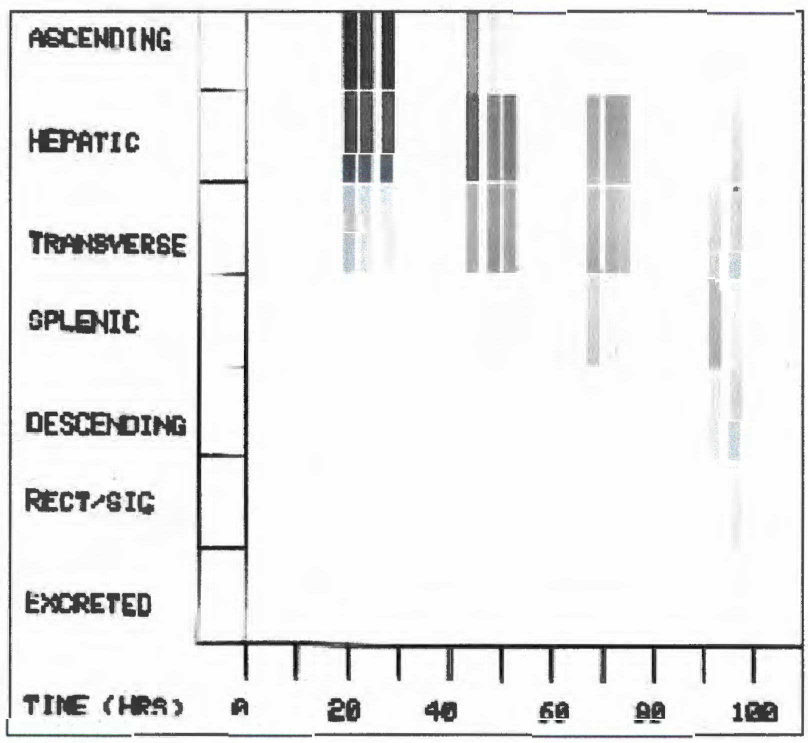
**GRAPH 15**



## Parametric images

On the parametric images (Figure 17) activity was seen in the ascending colon, hepatic flexure and transverse colon by 24 hours. Minimal activity was seen in the splenic flexure by 48 hours. The descending colon and recto-sigmoid were visible at 96 hours. No excretion was evident.

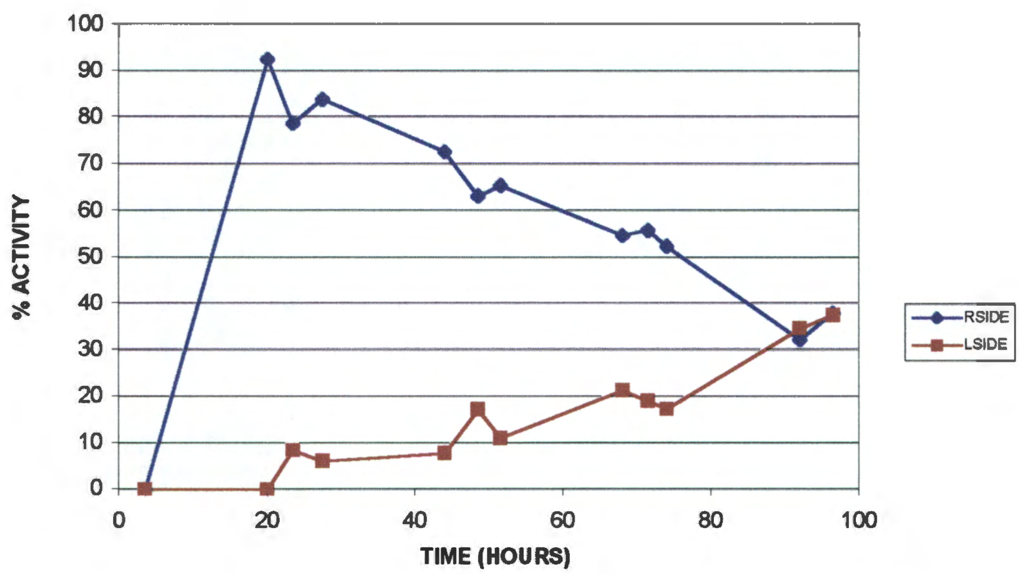
**FIGURE 17**



## Right and left sides of the colon

The time-activity graph of the arrival and clearance of activity in the right and left sides of the colon (Graph 16) showed 92% of the activity in the right side of the colon at 20 hours. It dropped slowly until at 75 hours there was 52% left in the right colon. Activity only appeared in the left colon (8%) at 24 hours and by 75 hours it had risen to 19%.

**GRAPH 16**




The analogue images clearly showed a pattern of right-sided delay as did the geometric centre, parametric images and the graph of the right and left sides transit of the colon.

This subject chose to have a colostomy because he had developed severe constipation. He was depressed because his bowel problems dominated his life. A right transverse end colostomy was performed. He is delighted with the results of his colostomy and the freedom it has given him.

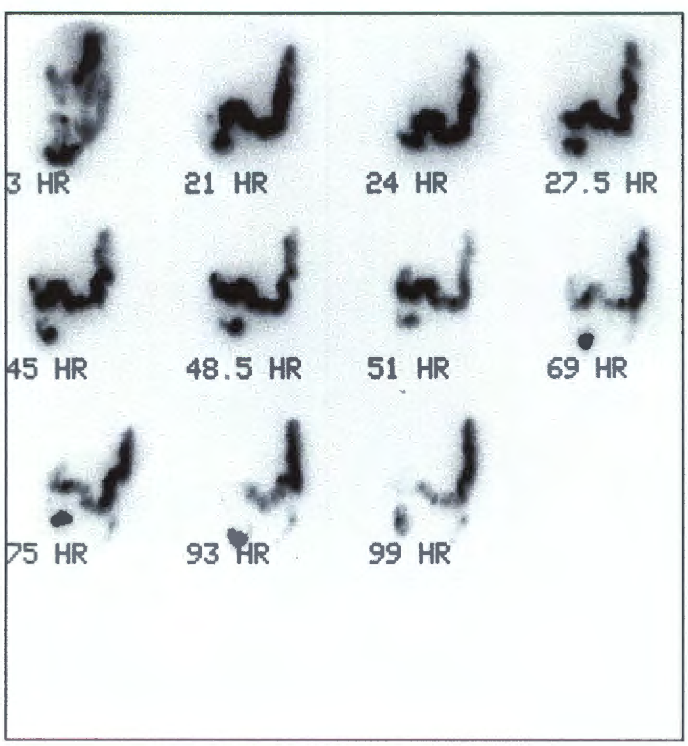
## SUBJECT 5

Subject 5 was 61 years old at the time of the study. Her spinal cord was injured at T12, seven years prior to this, following a spinal manipulation done under anaesthetic. She is motor complete and sensory incomplete and B on the Frankel Scale. She lives in a Residential Home where she has assistance. She was the only subject to use digital manipulation to empty her bowels and as a result had an atonic bowel and rectum.

### Analogue images

On the analogue images (Figure 18), the activity was spread between the caecum and the splenic flexure, at 24 hours. This picture remained unchanged until 69 hours when activity appeared in the descending colon and rectosigmoid. By 98 hours no change had occurred

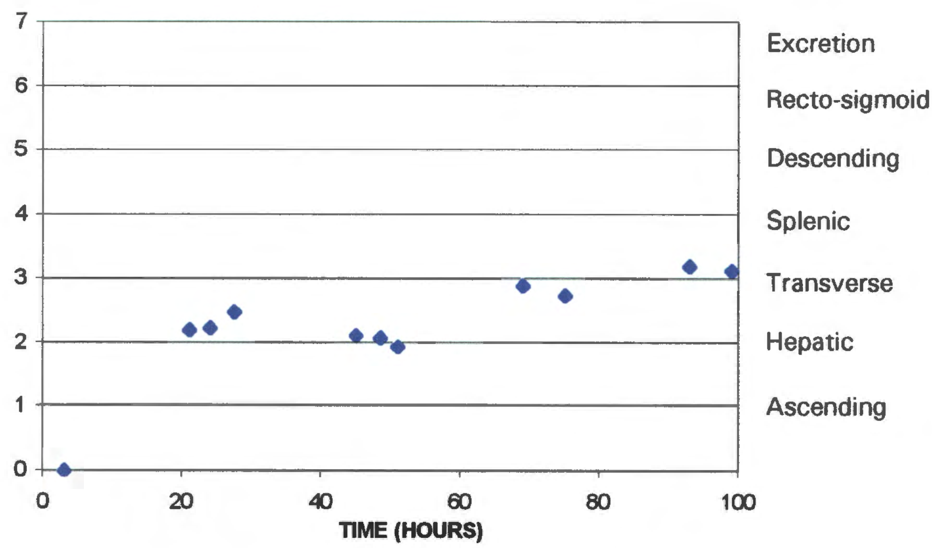
**FIGURE 18**



## Geometric centre

The geometric centre (Graph 17) lay distal to the hepatic flexure by 20 hours. At 27 hours it was situated proximal to the transverse colon. There was no change until 92 hours when the geometric centre lay just within the transverse colon.

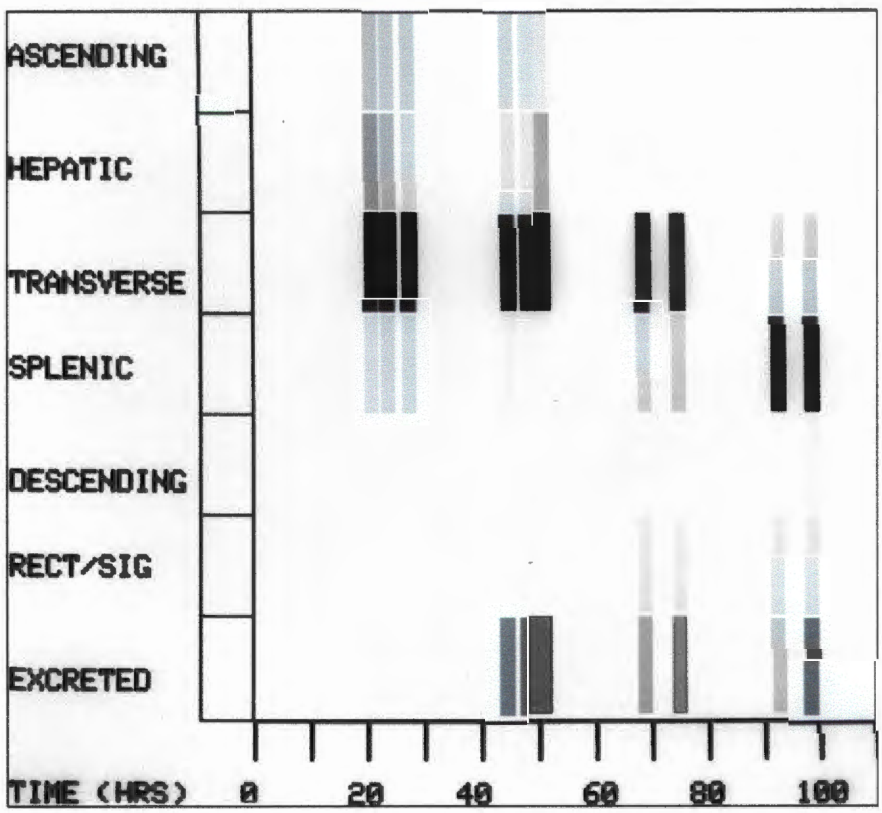
**GRAPH 17**



## Parametric images

On the parametric images (Figure 19) the bulk of the activity was seen in the transverse colon at 24 hours. Activity was seen in the splenic flexure at 98 hours. Excretion (17%) was seen at 45 hours on the parametric images.

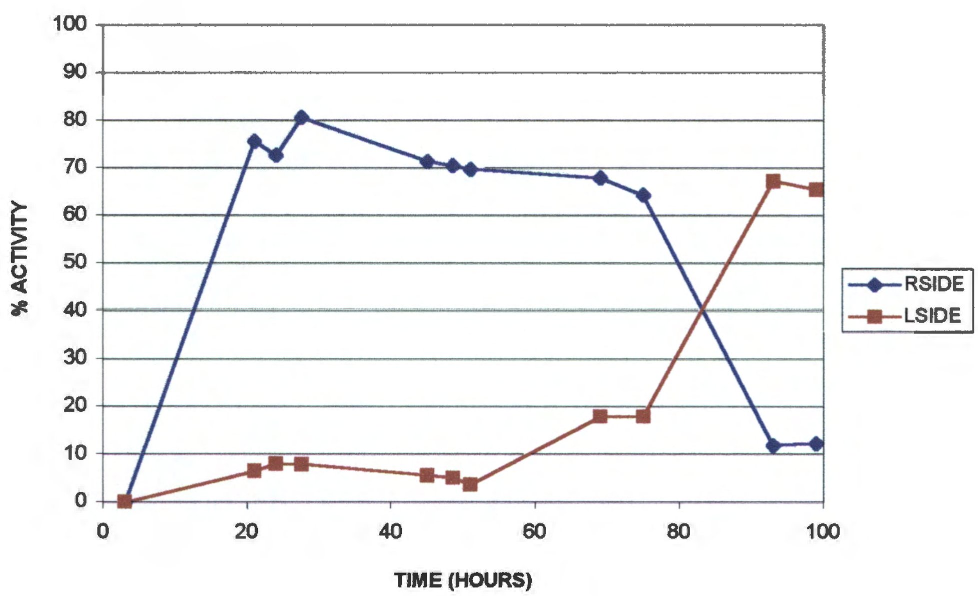
**FIGURE 19**



## Right and left sides of the colon

On the time-activity graph of the arrival and clearance of the activity in the right and left sides of the colon of the colon (Graph 18), the activity reached a peak in the right colon at 24 hours. By 75 hours it had only dropped to 70%. On the left side of the colon, the activity had only reached 12% by 75 hours.

**GRAPH 18**




The analogue images, geometric centre, and the graph of right and left sides of the colon both showed a pattern of right-sided delay. Despite the evidence of excretion (17%) at 44 hours on the parametric images, there was also evidence of right-sided delay. At 75 hours 53% of the activity was still within the transverse colon. The parametric images were, therefore also interpreted as right-sided delay.

Because she was incontinent this subject chose to have a colostomy, which was not altogether satisfactory and she had a repeat colostomy performed a year later with which she was satisfied.

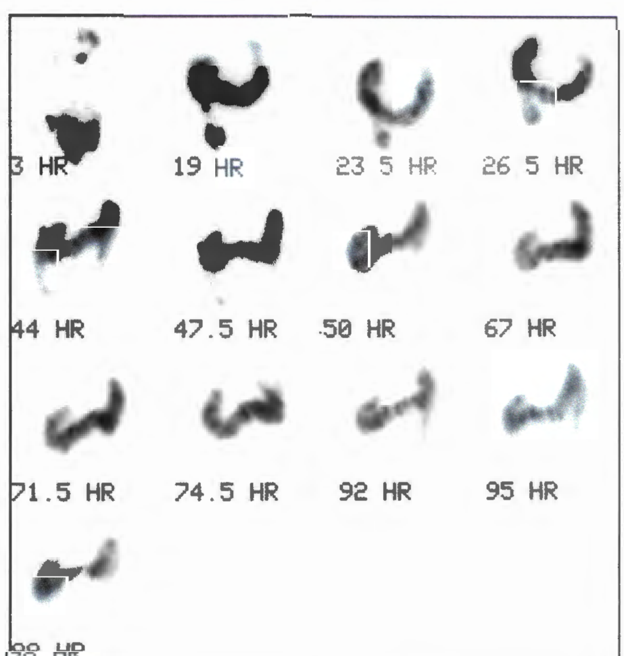
## SUBJECT 6

Subject 6 was 43 years old at the time of the study. She sustained a T12 spinal cord injury in a MVA 22 years previously. She was motor complete and sensory incomplete with a B rating on the Frankel Scale. She lives with her family and has had her right leg amputated because of bedsores. She never uses any laxatives or suppositories.

### Analogue images

On analogue images (Figure 20) some activity was still visible in the stomach and small bowel at 3 hours, although most had reached the right iliac fossa. By 24 hours the activity was dispersed from the ascending colon to distal transverse colon (42%). By 48 hours the ascending colon had emptied and the activity distributed from the hepatic to splenic flexure (80%). The activity remained in this position until 92 hours when it started to move into the proximal descending colon. The picture remained unchanged until the end of the study at 98 hours.

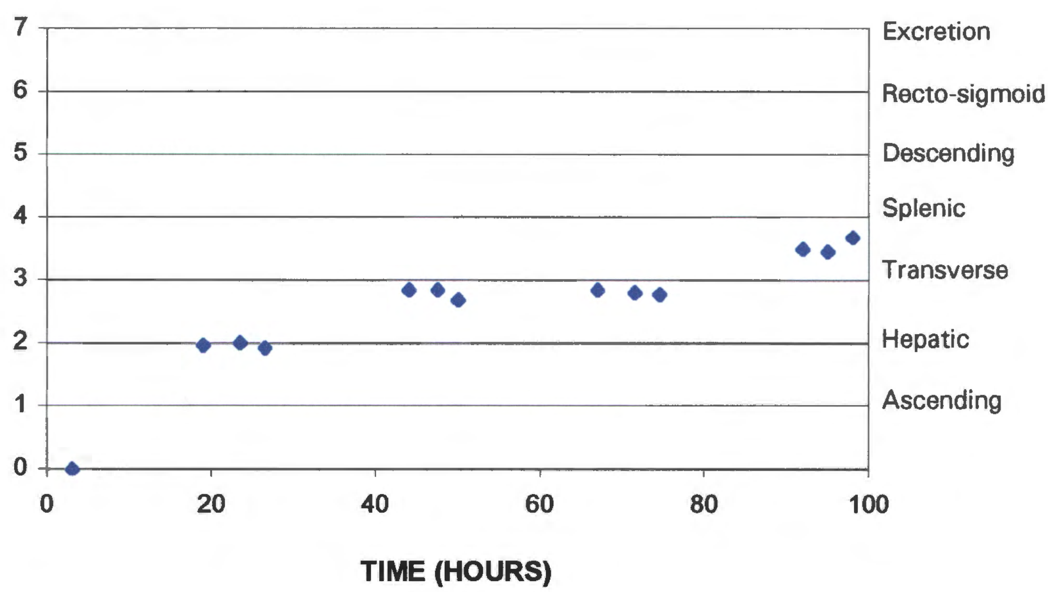
**FIGURE 20**



## Geometric centre

The geometric centre (Graph 19) was situated at the hepatic flexure on both the 20 and 24 hour images. By 44 hours it had moved into the transverse colon, where it remained for the next 30 hours. By 92 hours the geometric centre had moved into the distal transverse colon and remained there for the rest of the study.

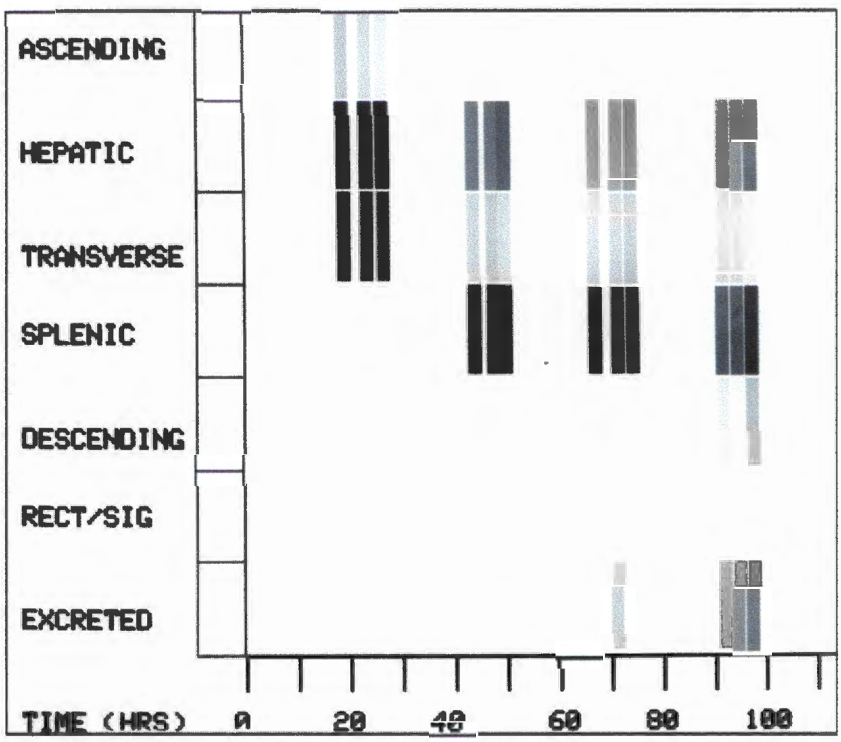
**GRAPH 19**



## Parametric images

The parametric images (Figure 21) agreed with the above picture excepting that excretion was seen at 72 hours.

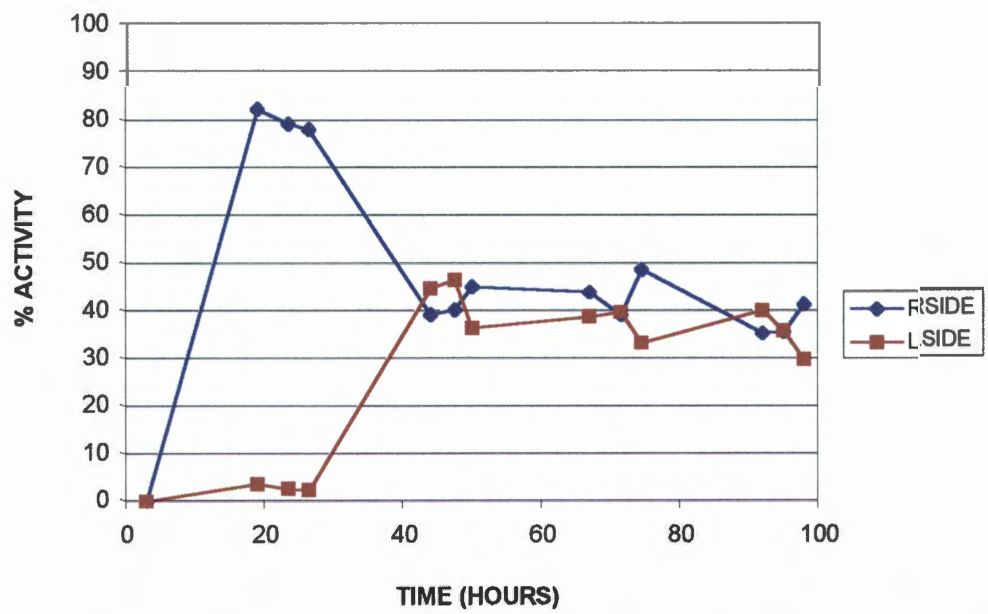
**FIGURE 21**



## Right and left sides of the colon

Graph 20 illustrates arrival and clearance of the activity in the right and left sides of the colon. Eight-two percent of the activity was seen within the right colon at 20 hours. The activity dropped steadily and by 51 hours had reached 43%. By 72 hours the activity had dropped to 40%. By 75 hours the activity had again risen to 49%. The activity in the left side reached its maximum (47%) at 44 hours. By 72 hours the activity in the left side had dropped to 40%. The activity in both sides of the colon was equal at this point. By 75 hours the activity in the left colon had dropped to 33%.

**GRAPH 20**




The analogue images, parametric images and geometric centre showed a pattern of right-sided delay. However the graph showing right and left sides of the colon was more indicative of generalised delay. This subject was classified as right-sided delay.

# LEFT-SIDED DELAY

## SUBJECT 7

Subject 7 was 46 years old at the time of the study. He received a compression fracture of T4/5 when he was assaulted, 20 years previously. He is motor and sensory complete with an A rating on the Frankel Scale. He is resident in a home for the physically handicapped and works once a week in sheltered employment. He has a hand-driven wheelchair.

### Analogue images

On the analogue images (Figure 22&23 anterior and posterior), activity was seen in the stomach and small bowel at 3 hours. By 24 hours the activity was seen in the ascending colon, hepatic flexure, transverse colon, and splenic flexure. By 48 hours the proximal descending colon was visualized and the ascending colon and hepatic flexure had emptied. The bulk of the activity lay in the splenic flexure (78%). The study ended at 75 hours and by then activity lay in the distal transverse colon, splenic flexure, descending colon and recto-sigmoid,

**FIGURE 22**

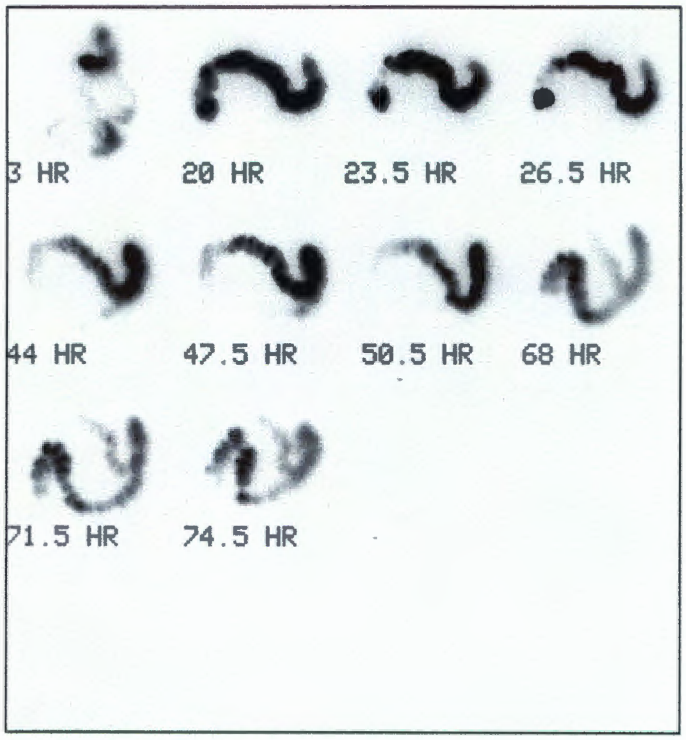
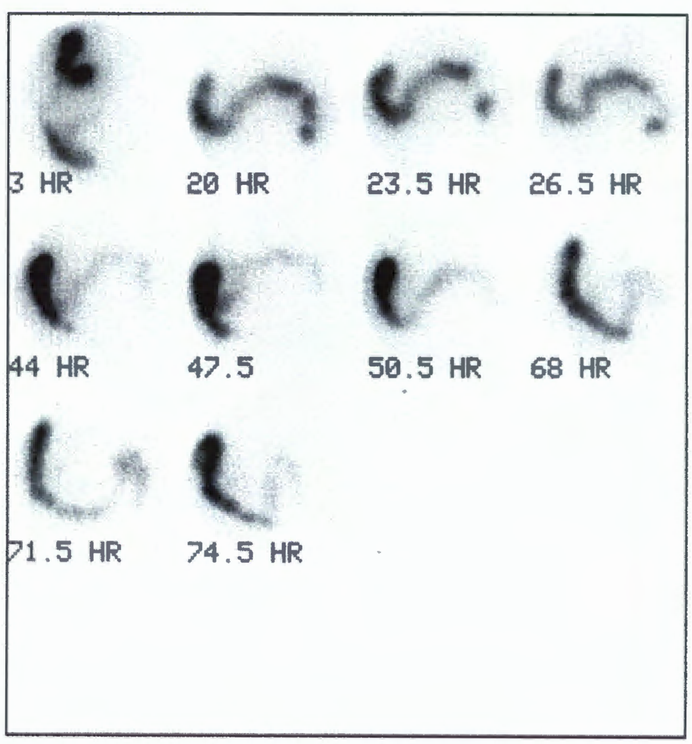


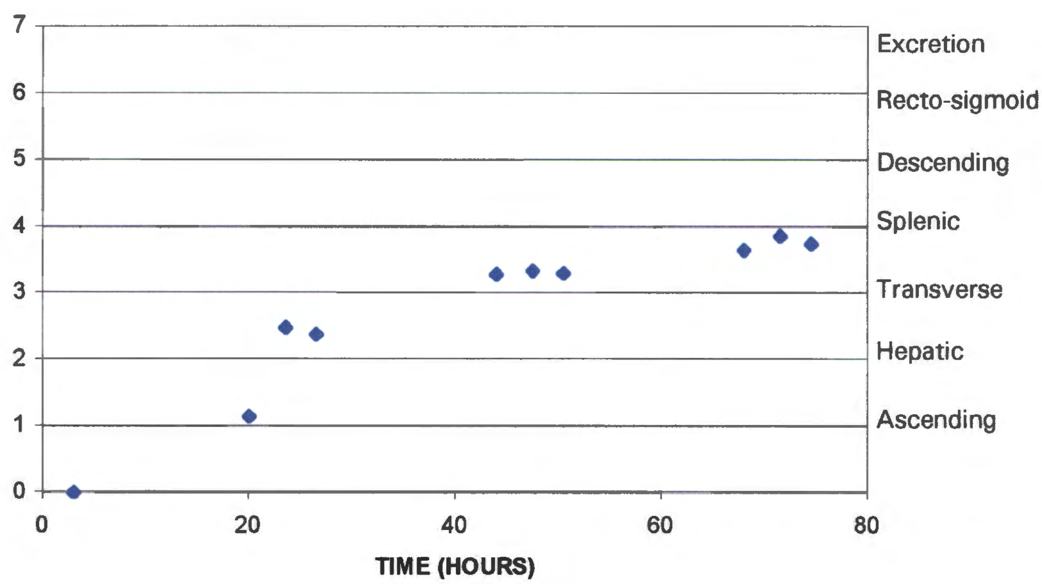

**FIGURE 23**



## Geometric Centre

The geometric centre (Graph 21) lay distal to the ascending colon at 20 hours. By 27 hours it had moved proximal to the transverse colon. At 44 hours the geometric centre lay distal to the transverse colon. By 69 hours it had moved proximal to the splenic flexure. It remained there until the end of the study at 75 hours.

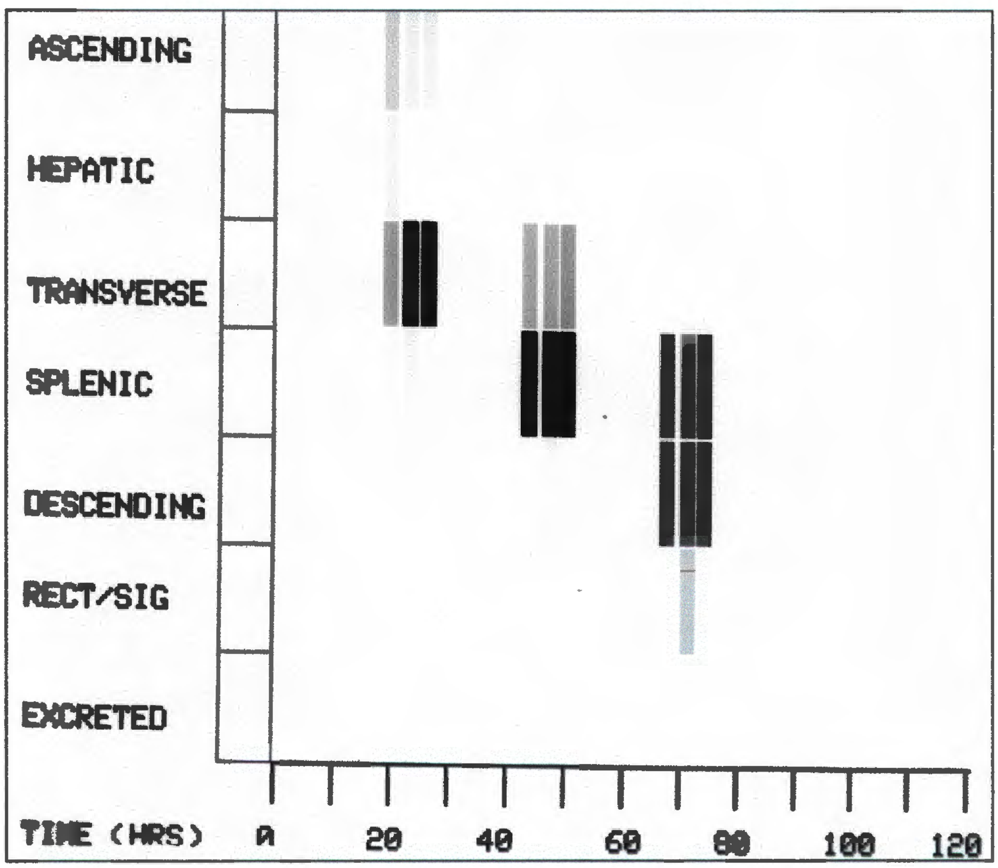
**GRAPH 21**



## Parametric images

The parametric images (Figure 23) showed activity in the transverse colon at 24 hours. It had reached the splenic flexure by 48 hours. By 75 hours the activity could be seen in the splenic flexure, descending colon and recto-sigmoid. No excretion was evident.

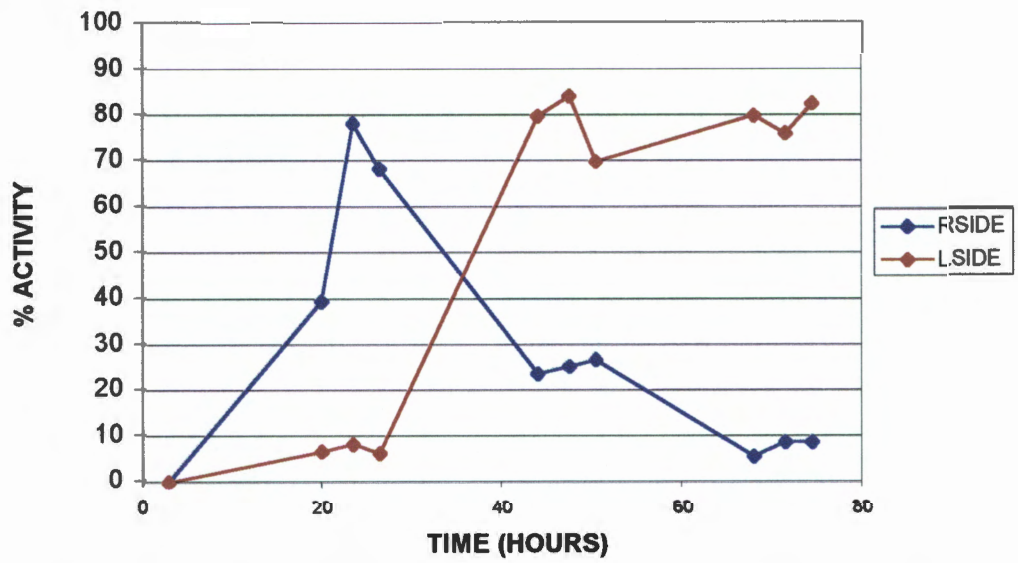
**FIGURE 24**



## Right and left side of the colon

On the time-activity graph of the arrival and clearance of the activity in the right and left sides of the colon (Graph 22), there was 40% of the activity in the right colon by 20 hours. This had risen to 79% by 24 hours. By 44 hours it had dropped to 24 %. By 75 hours it had dropped to 9%. By 27 hours there was only 7% of the activity present in the left colon but by 48 hours the activity had risen to 84%. It dropped to 70% at 51 hours but then rose again to 82% by 75 hours.

**GRAPH 22**




The analogue images showed a pattern of right- sided delay. However, the geometric centre, parametric images and the graph of the right and left sides of the colon were indicative of left-sided delay.

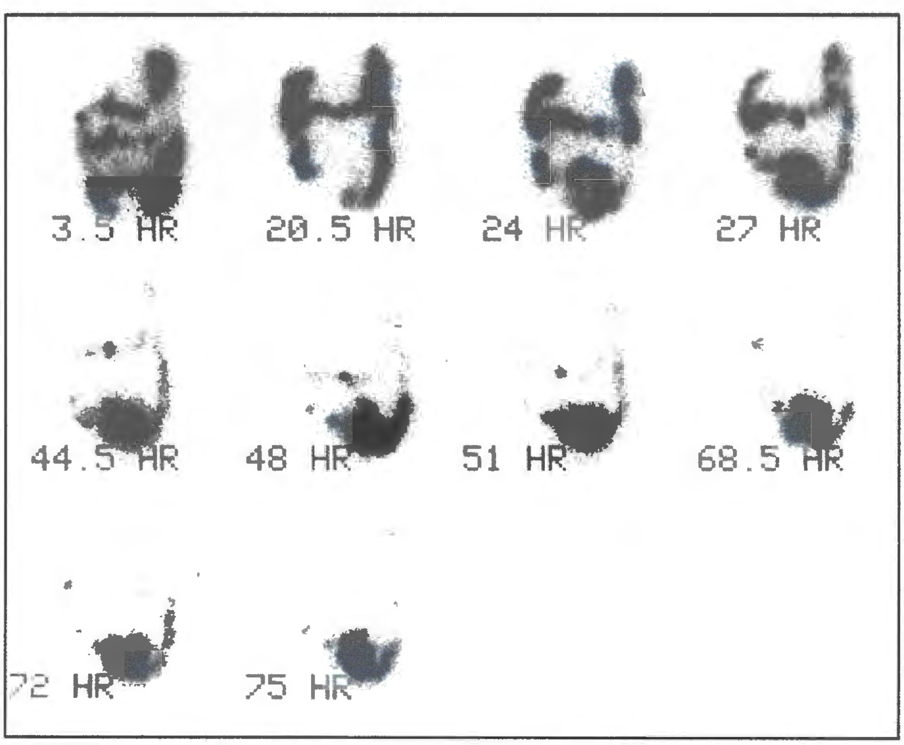
## SUBJECT 8

Subject number 8 was 46 years old at the time of the study. Her spinal cord was injured at T6 in a motor vehicle accident 23 years prior to the study. She lives in a home for the physically handicapped. She is motor and sensory complete and an A on the Frankel Scale. She is fairly independent as she has good use of her hands and arms. She is the only paraplegic who admitted to faecal excretion.

### Analogue images

On the analogue images (Figure 25), the activity was distributed throughout the colon with 25% having reached the recto-sigmoid, at 24 hours. By 48 hours the activity was localised in the distal descending colon and recto-sigmoid. At 75 hours the bulk of the remaining activity (43%) was in the rectosigmoid. This study was terminated early because of the lack of transport.

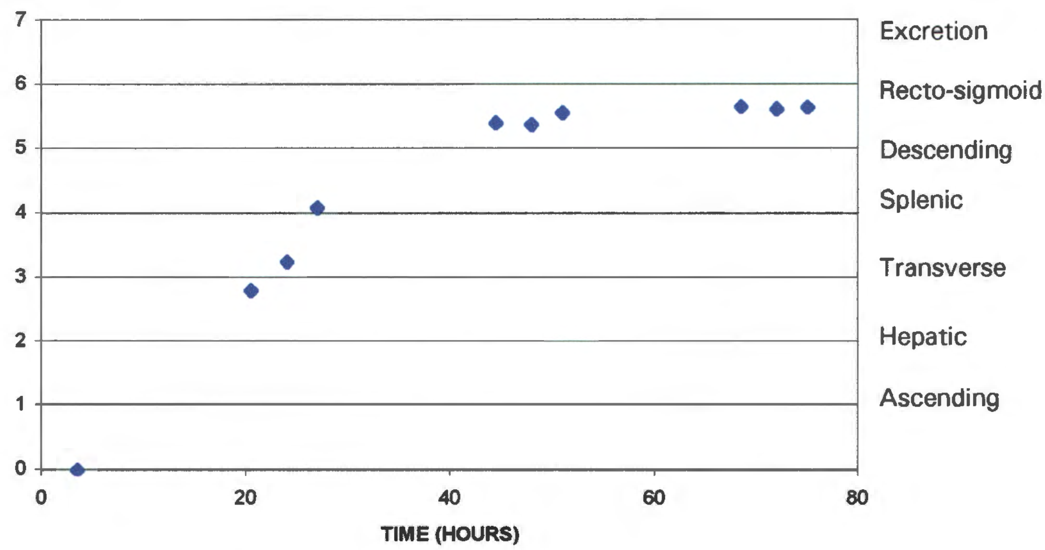
**FIGURE 25**



## Geometric centre

The geometric centre (Graph 23) was situated proximal to the transverse colon at 20 hours. By 27 hours it had moved distal to the splenic flexure. By 44 hours the geometric centre was positioned proximal to the rectosigmoid where it remained until the end of the study at 75 hours.

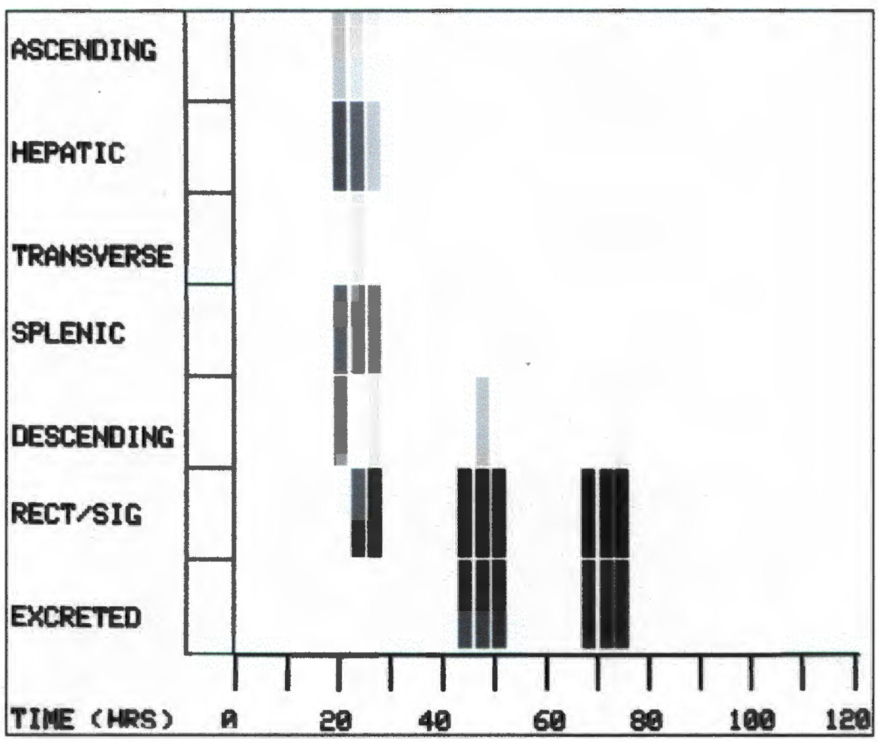
**GRAPH 23**



## Parametric images

On the parametric images (Figure 26), activity was distributed from the ascending colon to the recto-sigmoid at 24 hours. Excretion took place between the 27 hour and 44 hour images. By 48 hours the activity had cleared from the ascending colon, hepatic flexure, and transverse colon and was still visible in the descending colon and recto-sigmoid. At 75 hours activity was only visible in the rectosigmoid.

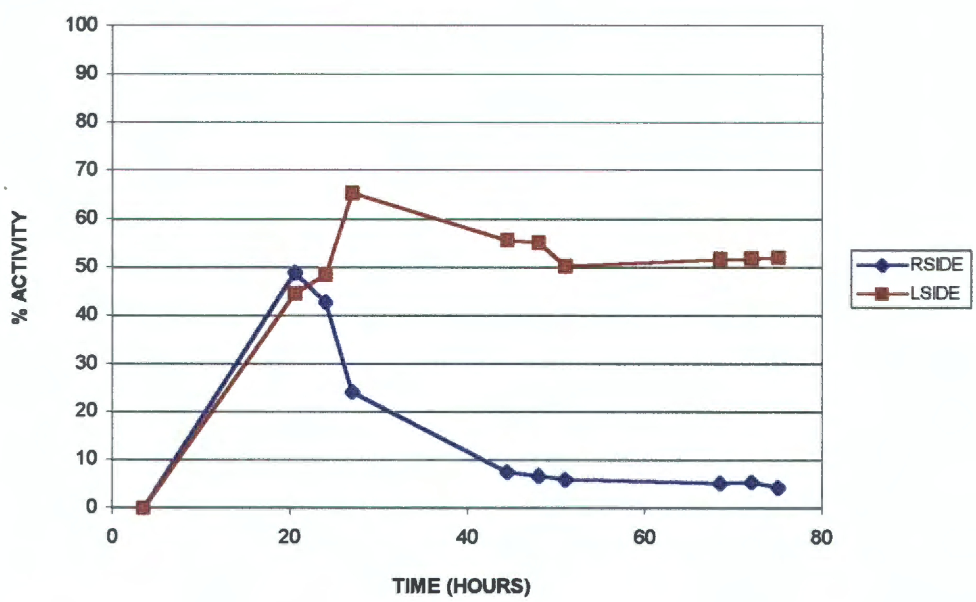
**FIGURE 26**



## Right and left sides of the colon

On the time-activity graph (Graph 24) of the arrival and clearance of the activity in the right and left sides of the colon, the right side reached a peak (50%) at 20 hours. The activity then began to drop until at 44 hours it reached 8% where it remained for the rest of the study. There was a steady rise in activity on the left side that reached a peak (66%) at 27 hours. By 51 hours it had dropped to 50% where it remained until the end of the study.

**GRAPH 24**




The analogue images showed an intermediate pattern of transit. Geometric centre was indicative of left-sided delay. The parametric images were also indicative of left-sided delay despite the fact that excretion (29%) had taken place by 44 hours. The parametric images showed a hold up in the recto-sigmoid from 27 hours (42%) until 75 hours (43%). This left sided delay is clearly seen on the graph of the right and left sides of the colon. This subject was categorized as left-sided delay.

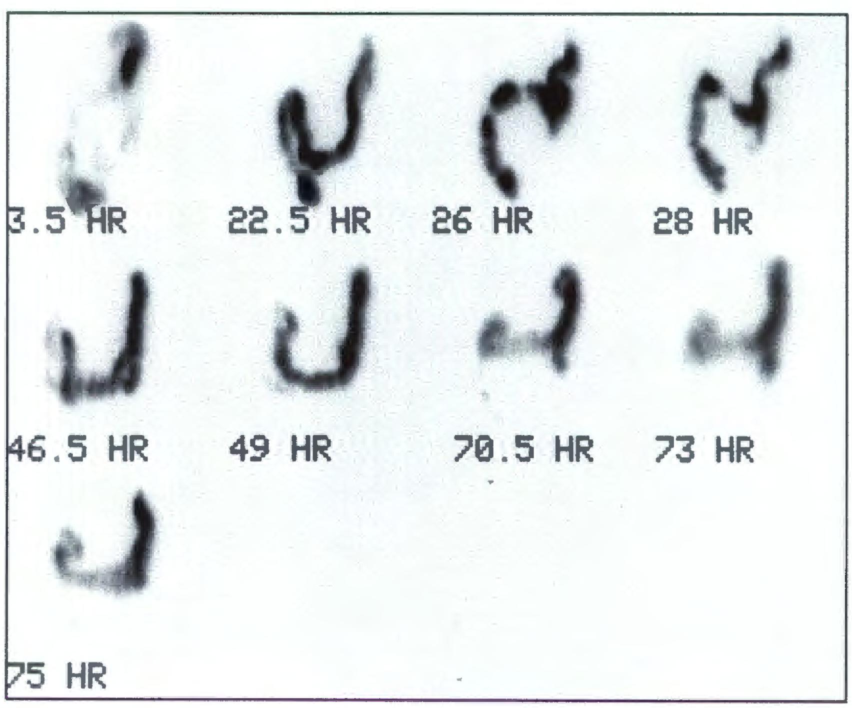
## SUBJECT 10

Subject 10 was 34 years old at the time of the study. His spinal cord was injured at C6, when he was assaulted five years previously. He is motor complete, sensory incomplete and rated B on the Frankel Scale. He lives in a home for the physically disabled.

### Analogue images

On the analogue images (Figure27), the activity was seen in the stomach and small bowel at 3 hours. By 24 hours the activity had spread from caecum to splenic flexure. By 48 hours the activity was no longer visible in the ascending colon but was seen in the hepatic flexure, transverse colon, and splenic flexure. It was difficult to visualise the descending colon as it was hidden behind the transverse colon. The distal end of the descending colon was clearly visible on the 69 hour image. The image remained unchanged at 75 hours, which was the final image in the study.

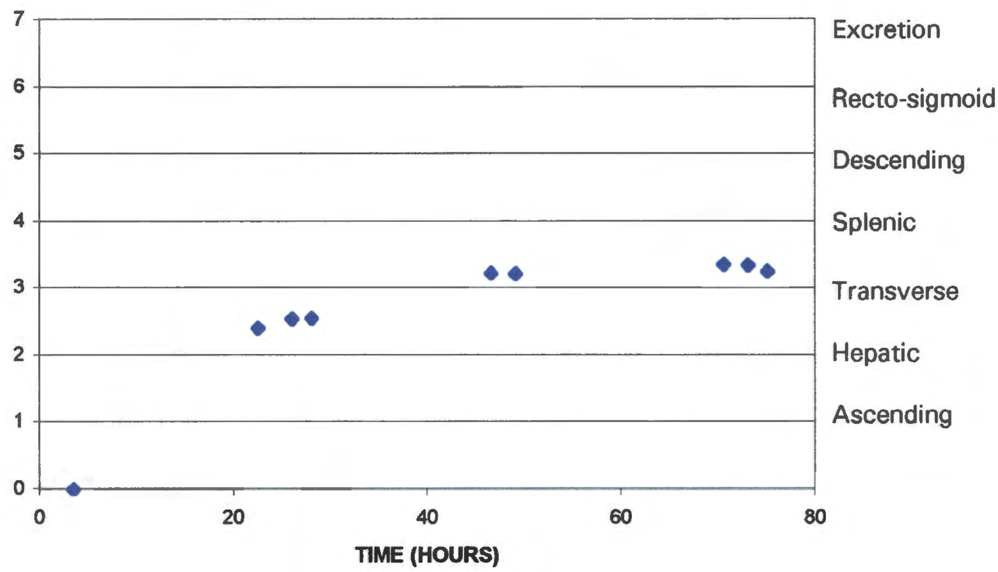
**FIGURE 27**



## Geometric centre

The geometric centre (Graph 25) lay distal to hepatic flexure by 24 hours where it remained until 27 hours. By 48 hours it lay distal to the transverse colon where it remained until the end of the study at 75 hours.

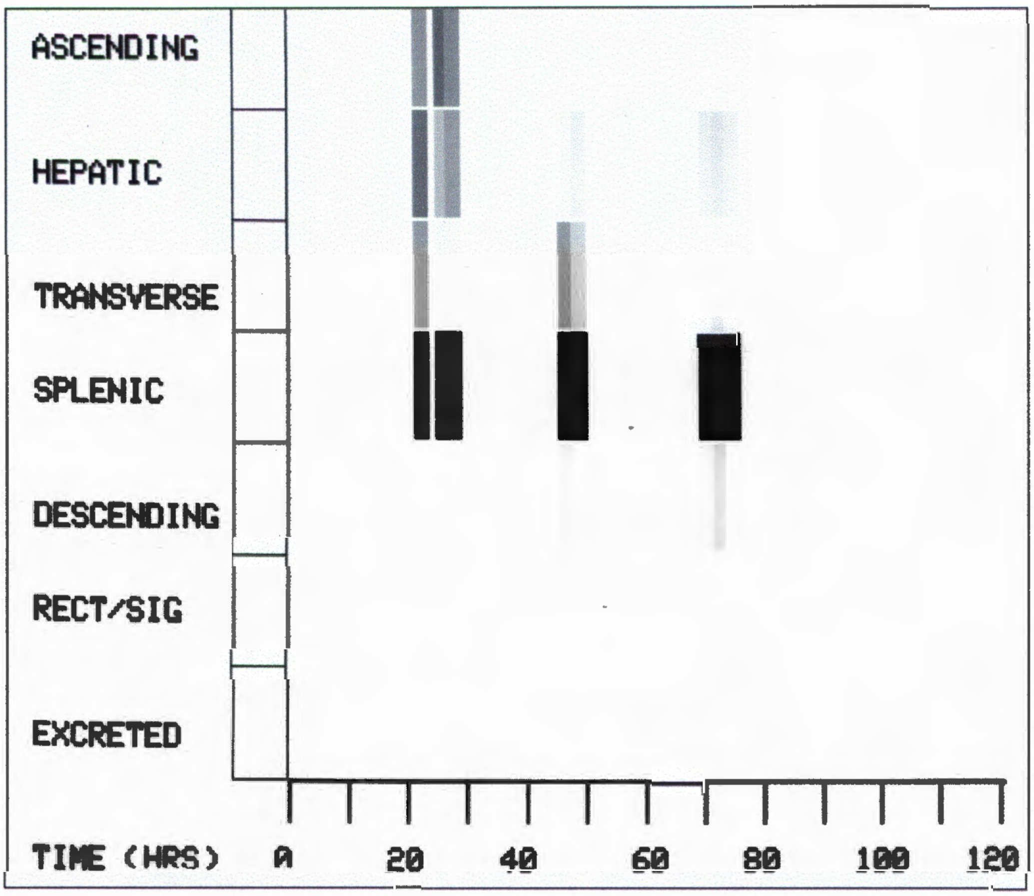
GRAPH 25



## Parametric images

The parametric images (Figure 28) showed the same pattern of transit seen on the analogue images. No excretion was shown.

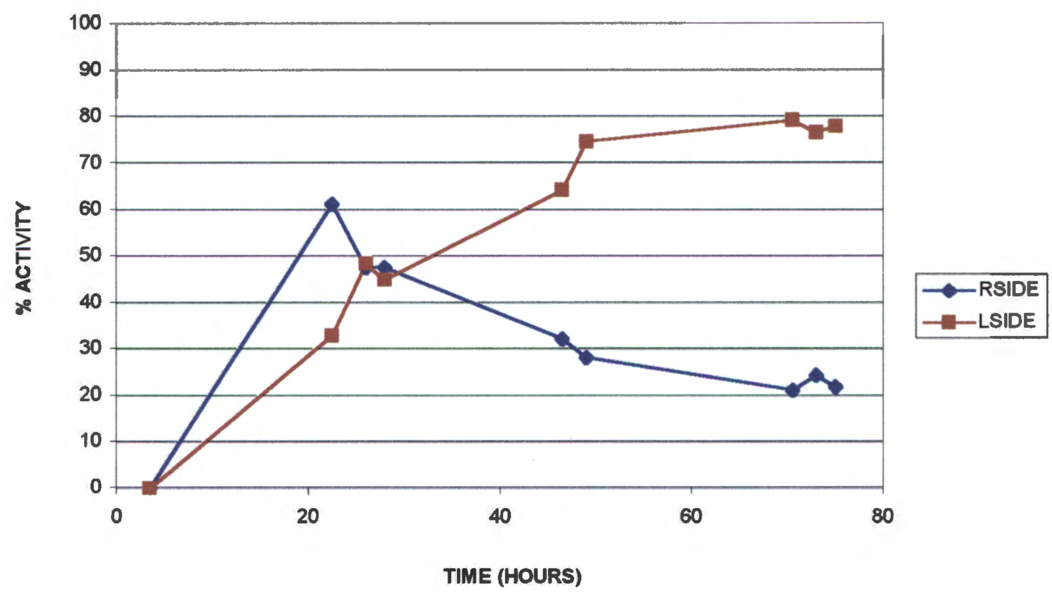
**FIGURE 28**



## Right and left sides of the colon

On the time-activity graph of the arrival and clearance of activity in the right and left sides of the colon (Graph 26), the activity in the right colon reached a peak (61%) at 24 hours. It then dropped slowly to 21% by 75 hours. The activity in the left colon rose slowly to 75% at 48 hours. By 75 hours it had reached 78%.

**GRAPH 26**




The analogue images showed a pattern of left-sided delay as did the geometric centre, parametric images and the graph of the arrival and clearance of activity in the right and left sides of the colon.

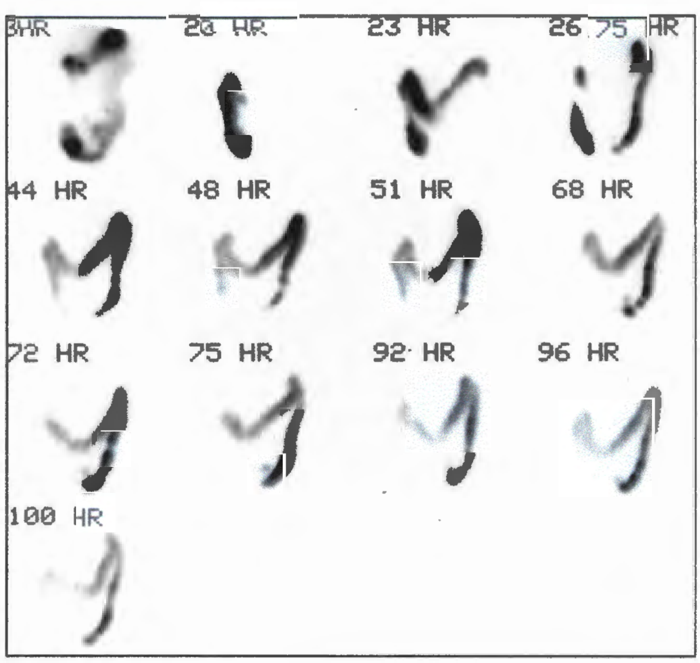
## SUBJECT 13

Subject 13 was 27 years old at the time of the study. He injured his spinal cord at C4, whilst playing rugby six years previously. He is motor complete and sensory incomplete with a B rating on the Frankel scale. He was a university student at the time of the study and he lived in a specially adapted student's residence, on campus, with a permanent care-giver. He is mobile with a motor-driven wheelchair and is extremely independent.

### Analogue images

On the analogue images (Figure29), the stomach and small bowel are visible at 3 hours. By 24 hours the activity was visible in the ascending colon, hepatic flexure, and the distal transverse colon. At 48 hours the activity was spread throughout the colon from ascending colon to descending colon. The activity had cleared from the ascending colon by 75 hours and the recto-sigmoid was visible. There was minimal retrograde movement of the activity back into the ascending colon at 96 and 98 hours.

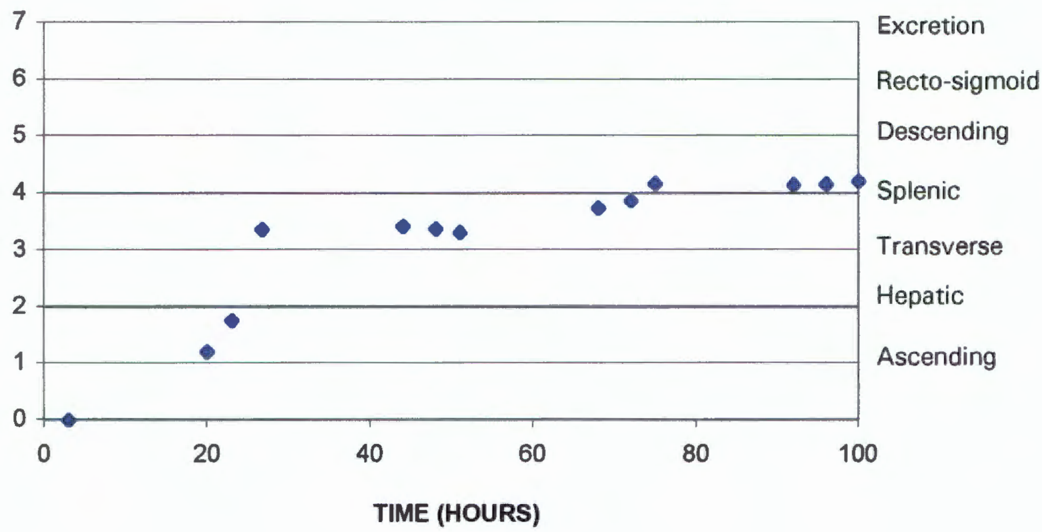
**FIGURE 29**



## Geometric centre

The geometric centre (Graph 27) lay distal to the hepatic flexure at 20 hours. By 27 hours it lay distal to the transverse colon where it remained until 51 hours. At 69 hours it lay proximal to the splenic flexure. By 72 hours it lay distal to the splenic flexure where it remained until the end of the study at 98 hours.

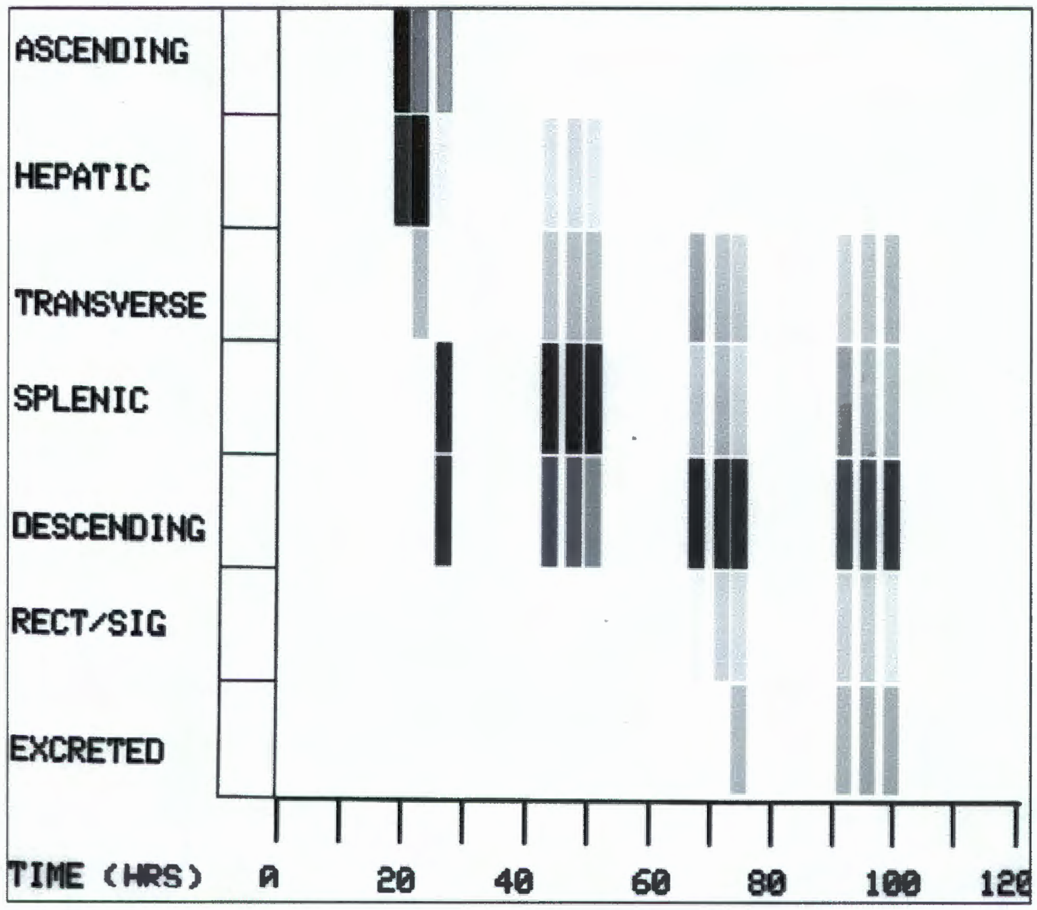
**GRAPH 27**



## Parametric images

The parametric images (Figure30) bear out the transit seen on the analogue images. Excretion was seen at 75 hours.

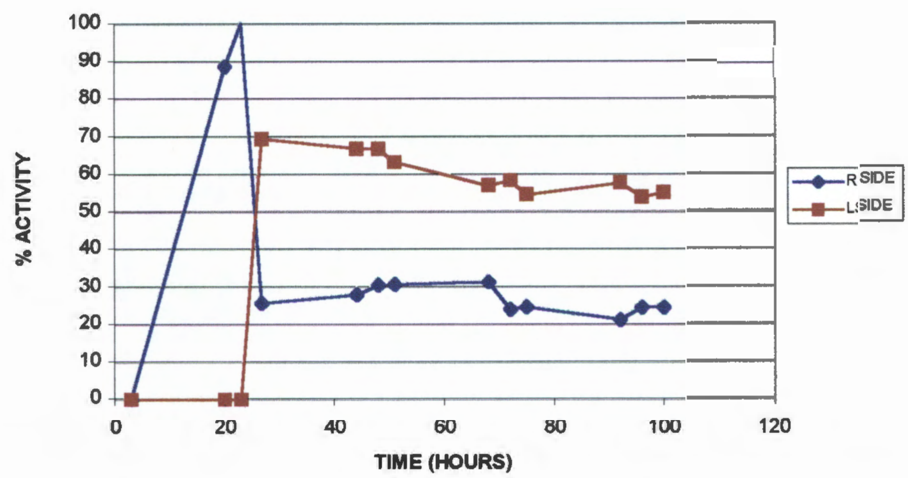
**FIGURE 30**



## Right and left sides of the colon

On the time-activity graph of the arrival and clearance of activity in the right and the left sides of the colon Graph 28), the activity in the right colon reached a peak (100%) at 24 hours. It then dropped suddenly to 25% at 27 hours. It remained at ± 30% until 75 hours when it dropped to 25%. The activity only appeared in the left colon (70%) at 27 hours. By 75 hours it had dropped to 59%.

**GRAPH 28**




The analogue images, geometric centre, parametric images and the graph comparing right side and left side transit through the colon are all indicative of left sided delay.

Subject 13 elected to have a colostomy, despite the fact that he had good control over his bowel regimen with cisapride and bisacodyl suppositories. He had severe abdominal pain and hoped the colostomy would alleviate this. A right transverse loop colostomy was performed because of the retrograde movement observed on scan. The colostomy did not relieve the pain but he is still delighted with the outcome as it has increased his independence.

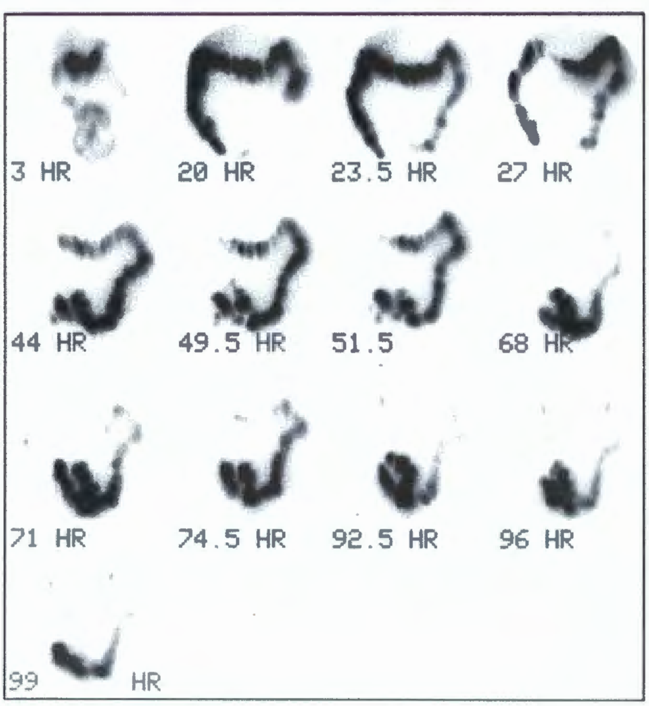
## SUBJECT 14

Subject 14 was 44 years old at the time of the study. He injured his spine at C6 in a motor vehicle accident 13 years previously. He is motor and sensory complete and an A rating on the Frankel Scale. He lives independently in a private house that was established for the physically handicapped. He is mobile in a motor-driven wheelchair.

### Analogue images

On the analogue images (Figure 31), activity was visible in the stomach and small bowel at 3 hours. By 24 hours the activity was spread from ascending colon to distal descending colon. By 48 hours the activity had cleared from the ascending colon and hepatic flexure and was visible in the rectosigmoid. At 75 hours the bulk of the activity lay within the rectosigmoid (39%) and the rest in the distal descending colon (30%). By 98 hours when the study was terminated 45% of the activity was seen in the recto-sigmoid and 19% within the distal descending colon.

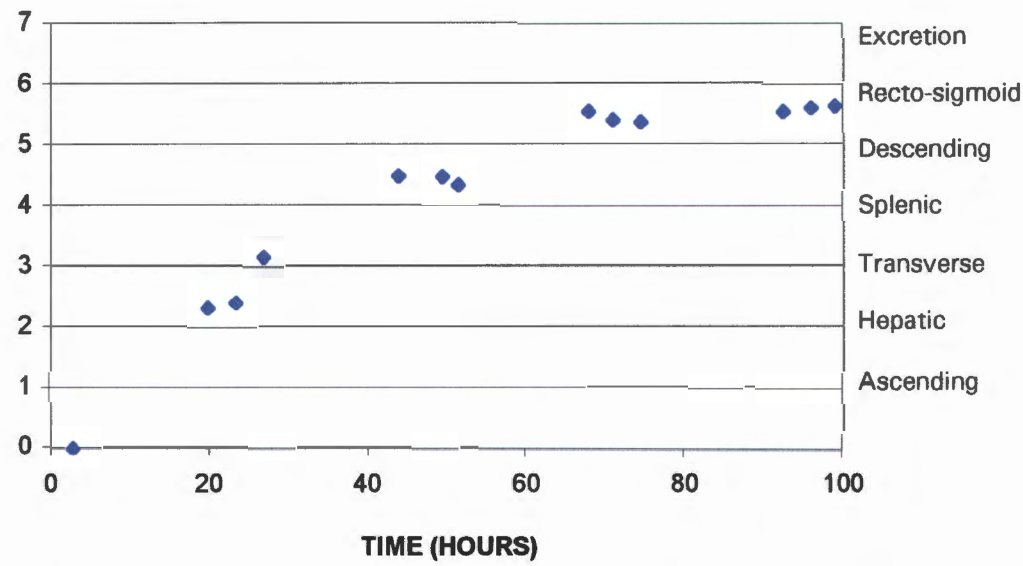
**FIGURE 31**



## Geometric centre

The geometric centre lay distal to the hepatic flexure at 20 hours (Graph 29). By 27 hours it had moved distal to the transverse colon. At 44 hours it lay proximal to the descending colon. By 69 hours the geometric centre lay proximal to the recto-sigmoid where it remained until the end of the study at 99 hours.

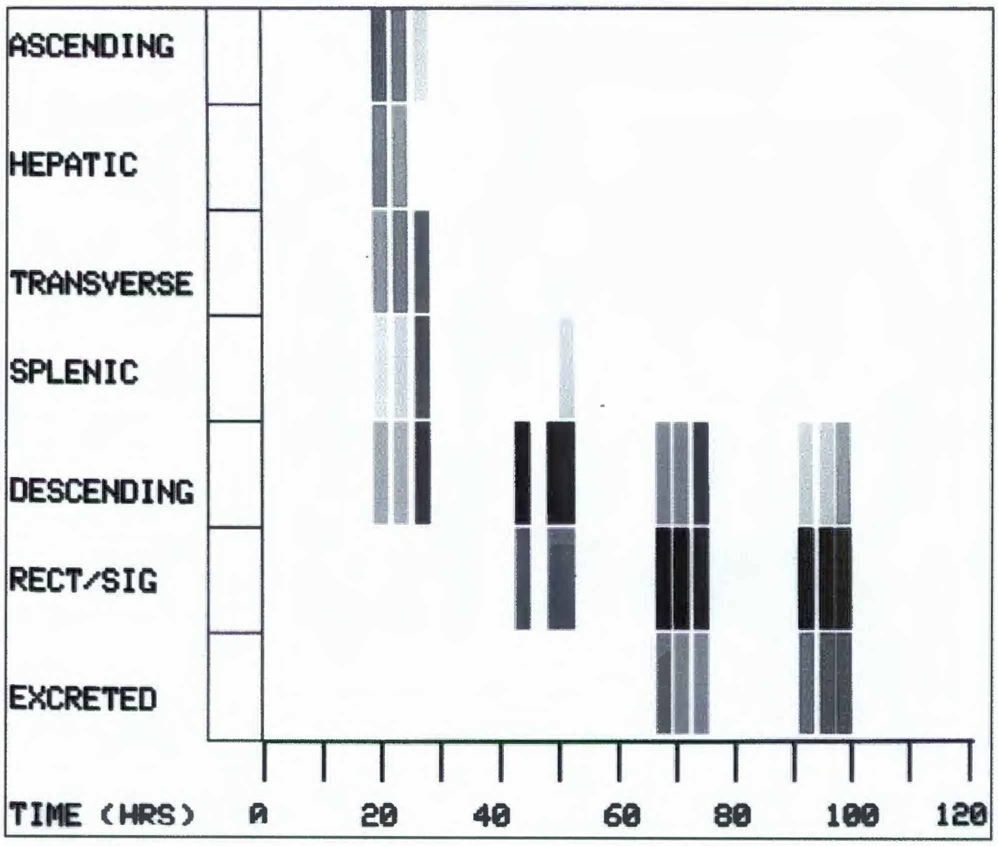
**GRAPH 29**



## Parametric images

The parametric images (Figure 32) showed the same colonic pattern seen on the analogue images. Excretion was seen at 68 hours.

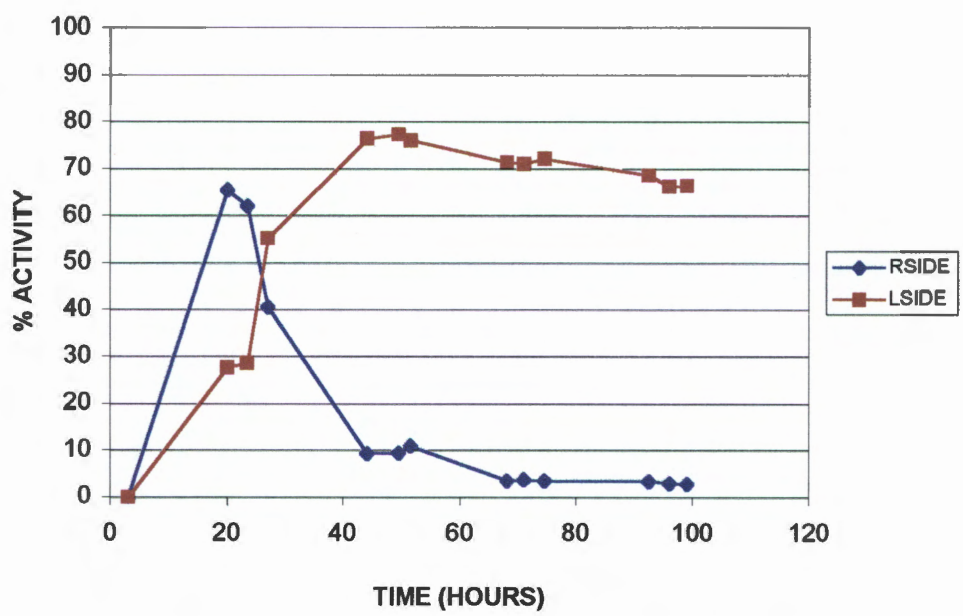
**FIGURE 32**



## Right and left sides of the colon

On the time-activity graph of the arrival and clearance of the activity through the right side with that of the left side of the colon, the activity in the right colon reached a peak at 20 hours. It then dropped steadily and at 75 hours only 5% of the activity was left in the right colon. The activity in the left colon rose to a peak (76%) by 44 hours and it dropped slowly to 71% by 75 hours.

**GRAPH 30**




The analogue images, geometric centre, parametric images, and the graph comparing right and left side transit through the colon were indicative of left sided delay.

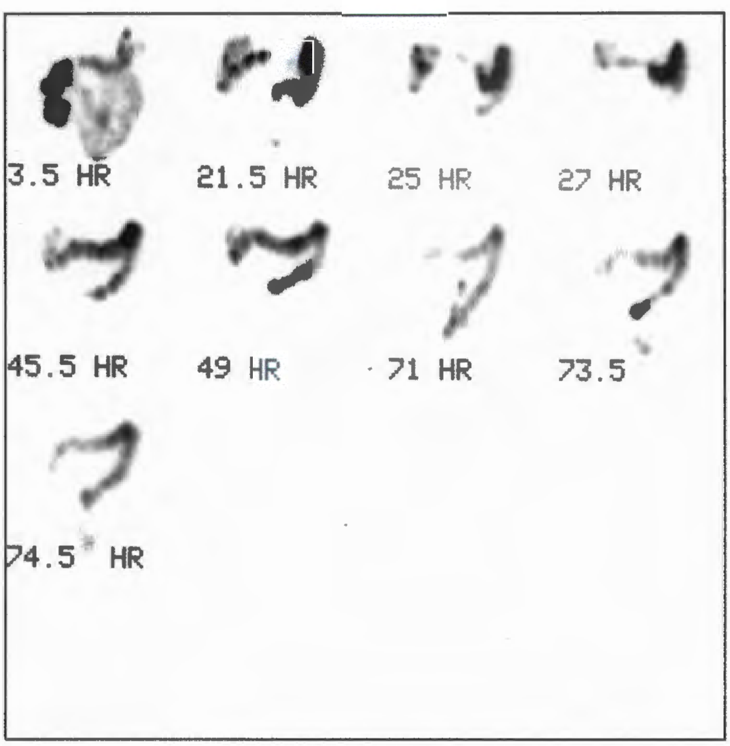
## SUBJECT 15

Subject 15 was 36 years old at the time of the study. He received his C5 spinal cord injury in a MVA 16 years previously. He is motor and sensory complete with an A rating on the Frankel Scale. He lives in a home for the physically handicapped.

### Analogue images

On the analogue images (Figure 33), the activity was seen in the stomach and small bowel at 3.hours. By 24 hours very little activity was seen in the distal ascending colon. Activity was seen in the hepatic flexure, transverse colon, splenic flexure (50%) and descending colon. By 48 hours the activity lay within the hepatic flexure (15%), transverse colon (19%), splenic flexure (23%) and descending colon (23%). The recto-sigmoid was visible from 72 hours until the end of the study at 75 hours.

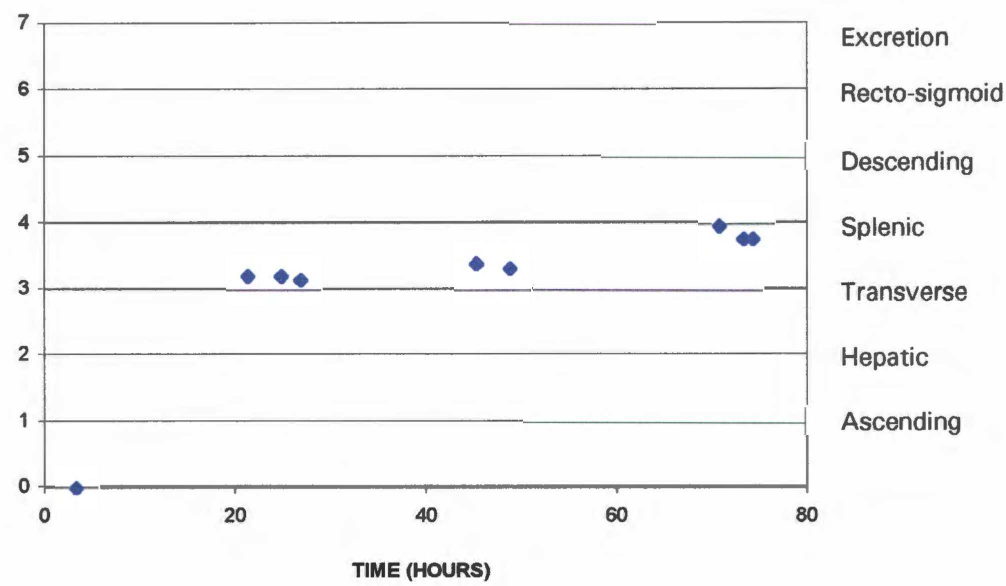
**FIGURE 33**



## Geometric centre

The geometric centre (Graph 31) was seen distal to the transverse colon at 20 hours. It remained in this position until 48 hours. At 72 hours it had moved proximal to the splenic flexure where it remained until the end of the study at 75 hours.

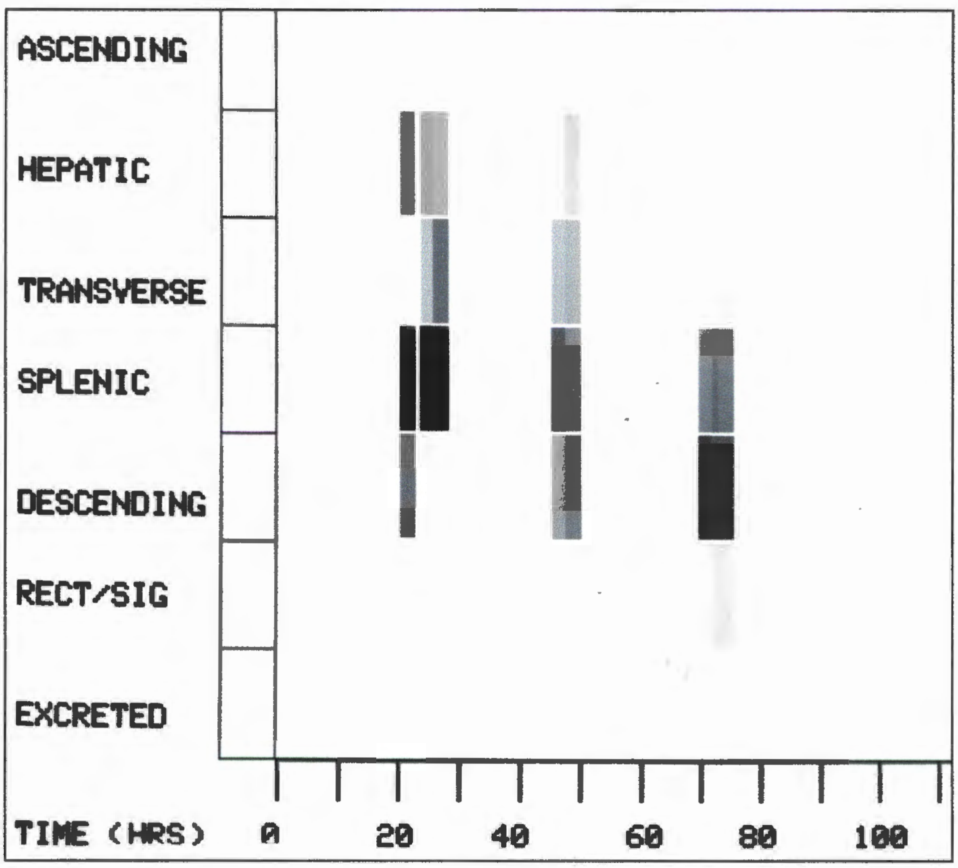
**GRAPH 31**



## Parametric images

On the parametric images (Figure 34) the hepatic flexure, transverse colon, splenic flexure and descending colon were visible at 24 hours. There was no change at 48 hours. By 72 hours the splenic flexure, descending colon and recto-sigmoid were visible. No excretion was seen.

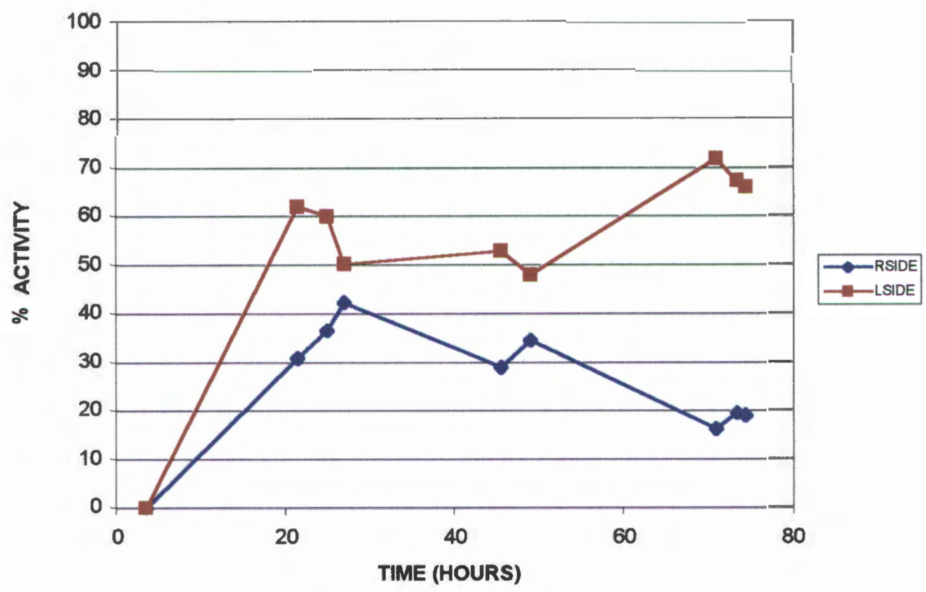
**FIGURE 34**



## Right and left sides of colon

The time-activity graph of the arrival and clearance of the activity in the right the colon and left sides of the colon (Graph32) showed 42% of the activity within the right colon by 27 hours. By 75 hours this had dropped to 20%. The activity in the left colon had risen to 62% by 20 hours. It dropped to 50% by 27 hour. It remained at about this level until 48 hours. Then it rose steeply reaching 72% at 72 hours. By 75 hours it had only dropped to 66%.

**GRAPH 32**




The analogue images were indicative of generalised delay. The parametric images and the graph of right and left sides of the colon were indicative of left-sided delay. The geometric centre showed a pattern of right-sided delay. This subject had retrograde movement of the activity from the splenic flexure to the transverse colon between 27 hours and 75 hours. This subject was classified as left-sided delay.

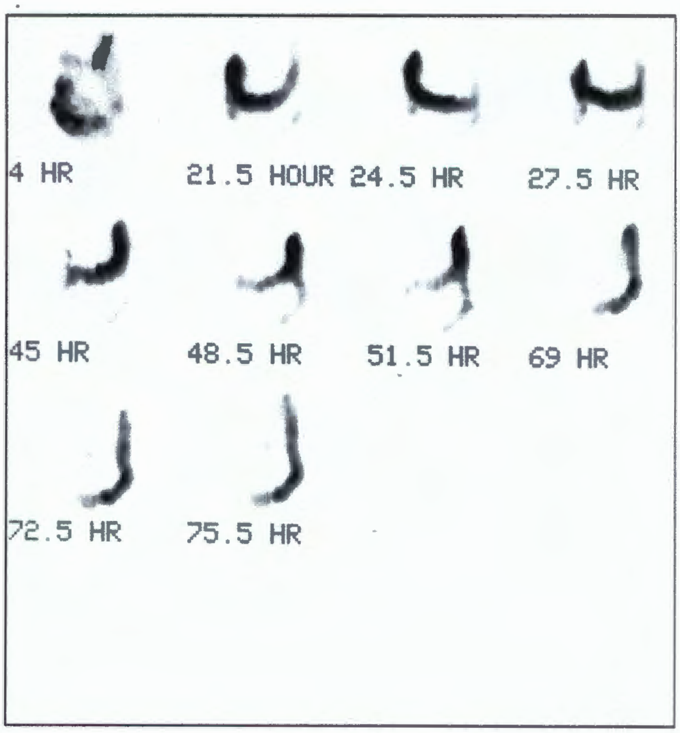
## SUBJECT 16

Subject 16 was 35 at the time of the study. He injured his spinal cord at C5 whilst playing rugby 12 years previously. He is motor complete and sensory incomplete with a B rating on the Frankel Scale. He lived in a home for the physically handicapped but died in an accident 2 years after the study. He was mobile in a hand-driven wheelchair.

### Analogue images

On the analogue images (Figure 35), the stomach and small bowel were visible at 3 hours. By 24 hours the activity was seen in the hepatic flexure (54%), and the transverse colon (28%). At 48 hours the activity had cleared from the ascending colon and hepatic flexure and was seen in the transverse colon, splenic flexure (71%) and the descending colon. By 75 hours when the study was terminated the activity lay mainly within the splenic flexure (28%), the descending colon (51%) and the rectosigmoid was visible.

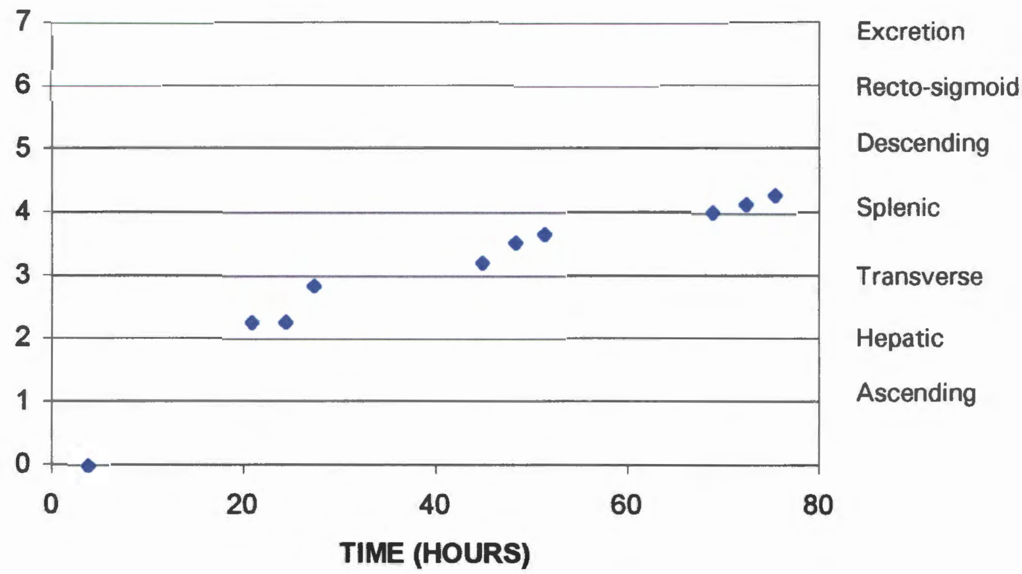
**FIGURE 35**



## Geometric centre

The geometric centre (Graph 33) was seen distal to the hepatic flexure at 20 hours. By 27 hours it was positioned proximal to the transverse colon. It lay proximal to the splenic flexure by 51 hours. By 69 hours it was positioned within the splenic flexure and by 75 hours the geometric centre lay distal to the splenic flexure.

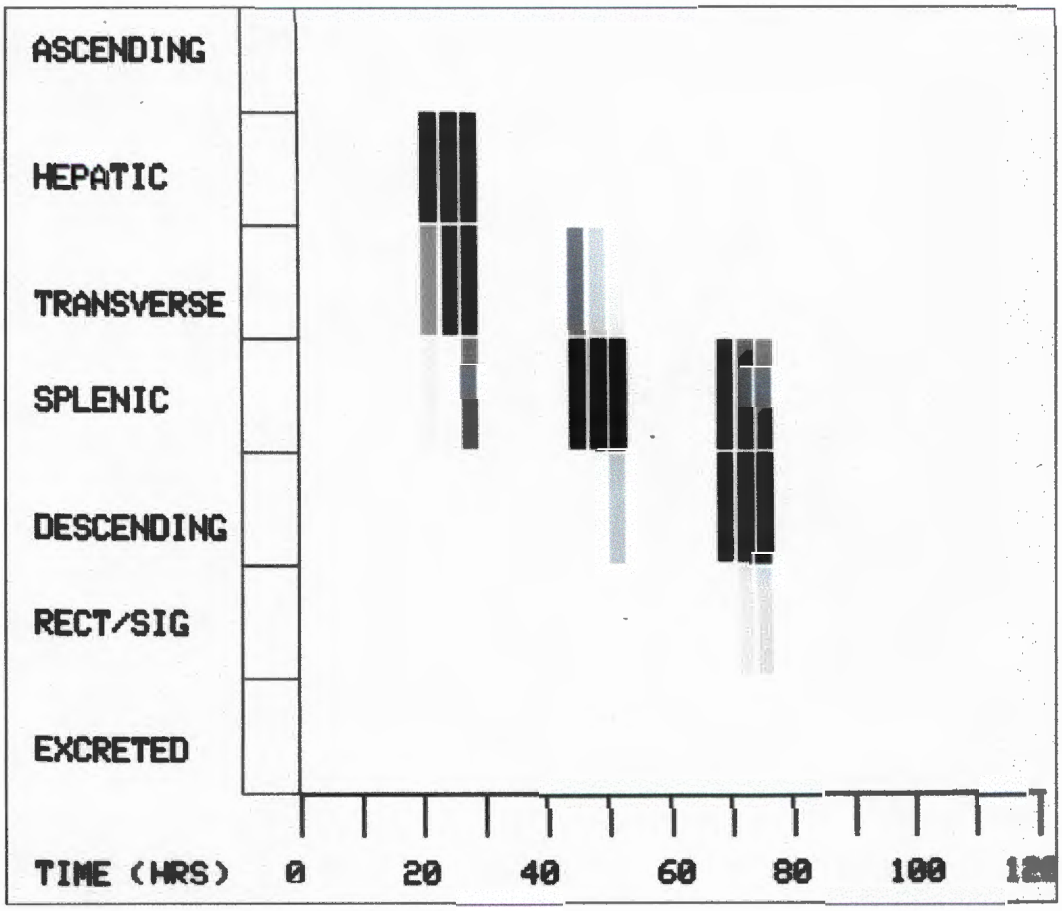
**GRAPH 33**



## Parametric images

The parametric images (Figure 36) showed the same transit pattern as the analogue images. No excretion was shown.

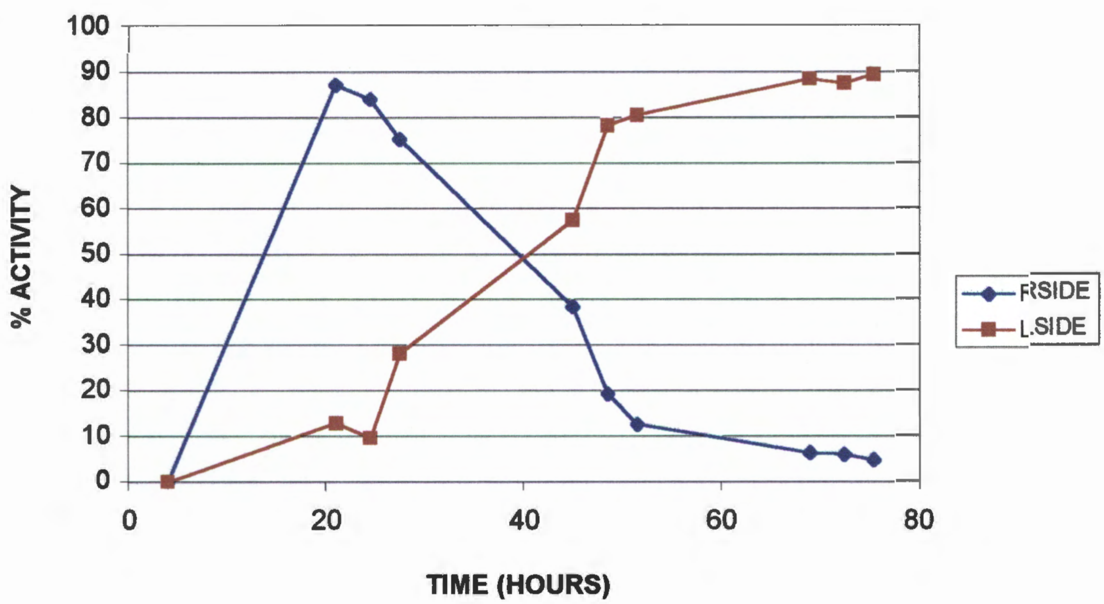
FIGURE 36



## Right and left sides of the colon

On the time-activity graph of arrival and clearance of the activity in the right and left sides of the colon (Graph 34), the activity in the right colon reached a peak (86%) 20 hours. It then dropped steadily until it reached 5% by 75 hours. The activity in the left colon rose to 80% by 48 hours. By 75 hours it had slowly risen to 90%.

**GRAPH 34**




The analogue images, geometric centre parametric images, and the graph of the right and left sides of the colon were all indicative of left-sided delay.